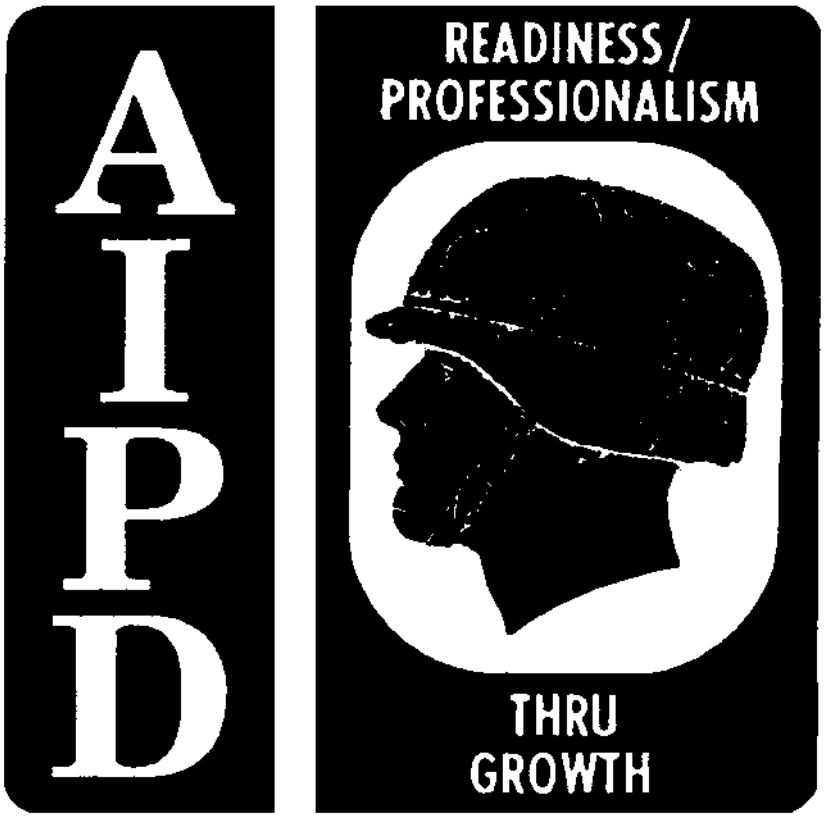
SUBCOURSE
MM0474

EDITION
8

POWER MEASUREMENTS



THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

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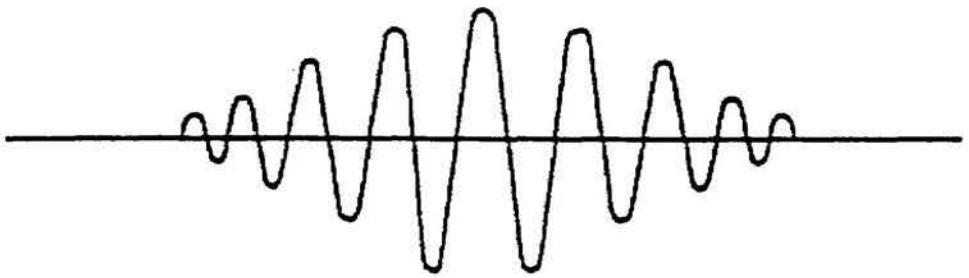

READ THIS PAGE

GENERAL INFORMATION

This subcourse consists of one or more lessons and an examination. Each of the lessons is divided into two parts, the text and the lesson exercises. For one lesson subcourses the lesson exercises serve as the examination. A heading at the beginning of each lesson gives the title, the hours of credit, and the objectives of the lesson. The final examination consists of questions covering the entire subcourse.

If a change sheet is included, be sure to post the changes before starting the subcourse.

THE TEXT

All the text material required for this subcourse is provided in the packet. The text is the information you must study. Read this very carefully. You may keep the text.

THE LESSON EXERCISES

Following the text of each lesson are the lesson exercises. After you have studied the text of each lesson, answer the lesson exercises. After you have answered all the questions, go back to the text and check your answers. Remember your answers should be based on what is in the text and not on your own experience or opinions. If there is a conflict, use the text in answering the question.

When you are satisfied with your answers, check them against the approved solution in back of this text. Re-study those areas where you have given an incorrect answer by checking the reference given after each answer.

THE EXAMINATION

After you have completed all the lessons and exercises, select the correct answer to all the examination questions. Carefully mark the correct answer on the exam response sheet. Be sure to include your social security number, subcourse number, and edition number are correct. Final exams should be mailed in the envelope provided. The exam will be graded and you will be notified of the results. Your final grade for the subcourse will be the some as your examination grade.

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ACKNOWLEDGEMENTS

Information and illustrations used to support the material in this subcourse were adopted from manufacturer's instruction manuals published by the following companies:

Hewlett Packard Company

National Bureau of Standards

SOLDIERS TASKS

This subcourse supports MOS 35H Calibration Specialist Soldiers Manual Task 093-435-2242, Calibrate Power Meter Calibrator stated in FM 9-35H1/2. This subcourse also supports Task 093-435-3606, Repair Microwave Synchronizer and 093-435-3232, Calibrate Waveguide Directional Coupler as stated in FM 9-35H3.

CORRESPONDENCE COURSE
OF THE
U.S. ARMY MISSILE AND MUNITIONS
CENTER AND SCHOOL

AIPD SUBCOURSE NUMBER MM0474

POWER MEASUREMENTS
(13 Credit Hours)

INTRODUCTION

Considerable information regarding power has been published over the years, some of which discusses the subject in great detail. The purpose of this subcourse is to present a composite reference of techniques, instruments and standards used in the measuring of microwave power.

This subcourse is not designed to make you an expert. However, if you have had experience with power measurements, then this subcourse will be more meaningful.

This subcourse is not intended as instruction in basic electronics. For example, when discussing a RF Detection Bridge or an oscillator amplifier, it will be assumed the student knows how a RF Detection Bridge or an oscillator amplifier operates. The subcourse is technically written only to the depth necessary to tie the circuit to the overall operation of the instrument. Unusual circuits will be explained in greater detail. When the equipment is covered in other correspondence subcourses, only the subcourse number will be referenced.

This subcourse consists of five lessons and an examination organized as follows:

Lesson 1.	Introduction to Power Measurements	1 hour
Lesson 2.	Power Measurement Equipment - Part I	4 hours
Lesson 3.	Power Measurement Equipment - Part II	2 hours
Lesson 4.	Power Measurement Equipment - Part III	3 hours
Lesson 5.	Power Measurement Techniques	2 hours
Examination		1 hour

LESSON 1. INTRODUCTION TO POWER MEASUREMENT

AIPD SUBCOURSE NUMBER MM0474.....Power Measurements

LESSON OBJECTIVE.....After studying this lesson you will be able to explain the purpose, principles of operation and types of units used for power measurements.

CREDIT HOURS.....One

TEXT

1. GENERAL.

a. When electronic power flows in a transmission line at low frequencies, there is definite current flowing in each line conductor, and a definite voltage across any two terminals of the line. Because of this, power is usually measured in terms of voltage, current and power factor. Impedance magnitude is defined as the ratio of voltage to current. Also, meters exist which measure power and impedance directly. These instruments read the product of voltage, current and power factor, or the ratio of voltage to current.

b. At frequencies of 400 MHz or higher, it is difficult to describe circuit performance with the conventional concepts of current and voltage. For example, the voltage supplied to a rectangular waveguide by a UHF oscillator, or the current drawn by a cavity, varies depending on the terminal plane at which these quantities are measured. Furthermore, there are no electrodynamic instruments available for measurements at microwave frequencies, so that crystal and thermal detectors are generally employed in specially calibrated circuits to permit the measurement of voltage, current and impedance. However, absolute power may readily be measured at microwave frequencies by means of various types of thermally sensitive elements. These elements and methods for using them are the subject of this subcourse.

2. THE NATURE OF MICROWAVE POWER AND POWER MEASUREMENTS.

a. Micro Power.

(1) Power measurements at microwave frequencies are subdivided into several categories usually depending on power level, waveform, and frequency. These subdivisions are arbitrary and based to a large extent upon the type of measuring equipment available. Power is divided into three levels, low, medium and high, covering ranges from 0 to 10 mW, 10 mW to 1 Watt and above 1 Watt. Microwave power meters usually handle one power range. Low-power measurements are made with devices

specifically designed to measure low levels of power. High-power measurements are made, both with special high-power measuring devices and with calibrated attenuators designed to reduce the power by a known amount, to a level that can be measured by low level type devices. Medium-power levels are usually measured by low power meters used in conjunction with calibrated attenuators.

(2) Most power-measuring devices respond only to average power, that is, if the power source consists of some form of low frequency amplitude modulation of an RF signal, the power meter will read the average of the power over a number of cycles. In many applications, microwave power flows as a constant-amplitude (CW) wave which is amplitude modulated by a square wave or sine wave, or pulse modulated by pulses whose pulse repetition frequencies are in the audio range. Illustrated in Figure 1 are some typical microwave power waveforms. In all these cases the power meters commonly used to measure microwave power read the average power over several cycles of pulses of the modulation frequency. For pulsed power it is frequently necessary to know the peak power. This can be found from the average power by the formula:

$$P_o = \frac{P}{Tf_r}$$

where:

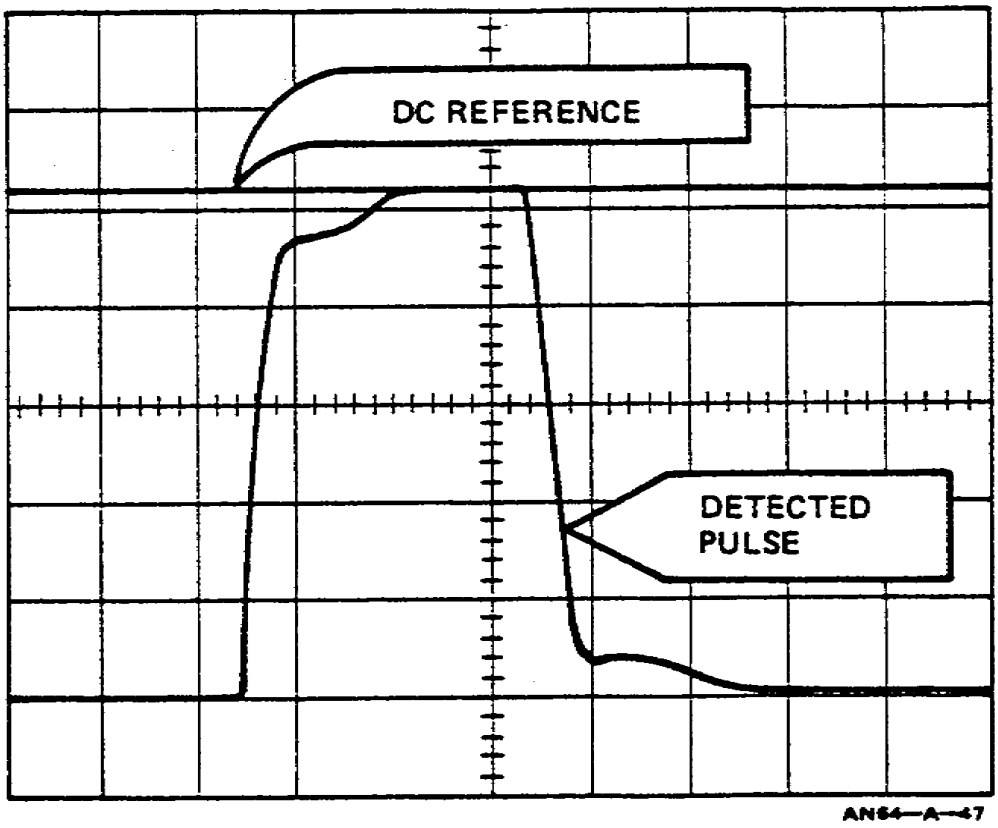
P_o = peak pulse power in watts
P = average power in watts
T = pulse length in seconds
f_r = pulse repetition frequency in pulses/sec.

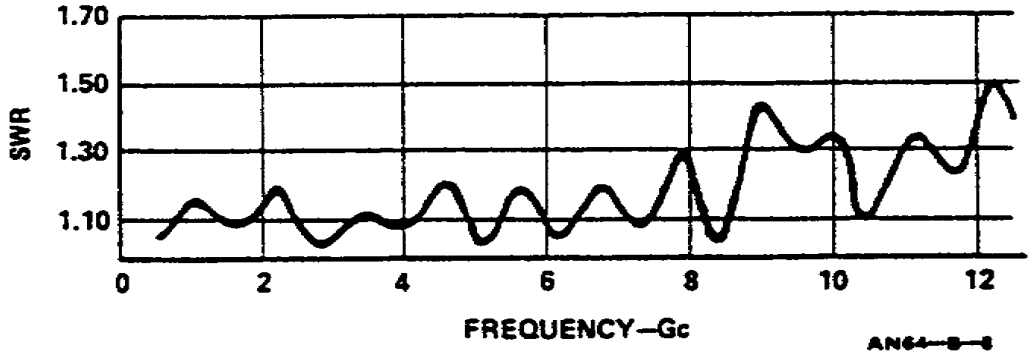
The quantity Tf_r describes the nature of the pulses power. It is equal to P/P_o and is called the "duty cycle" of the pulsed wave.

b. Nature of power-sensitive elements.

(1) The response of a device to the temperature rise caused by the dissipation of electrical power is the fundamental basis of microwave power measurements. Thermal devices for power measurements include three general types, thermocouples, bolometers, and calorimeters.

(2) A thermal junction occurs at the point where two dissimilar metal wires are connected in series. A temperature difference between junctions produces an emf, that is proportional to the difference, which can be metered by a DC instrument. A thermocouple may be used to measure the temperature rise of a load which dissipates microwave power. Appropriate calibration converts this temperature rise into an indication of microwave power.





INPUT SWR OF A TYPICAL hp 434A CALORIMETRIC POWER METER. BROADBAND IMPEDANCE IS CAREFULLY CONTROLLED BY TERMINATING INPUT POWER IN A COAXIAL FILM RESISTOR IN A TAPERED OUTER CONDUCTOR.

Figure 1. Power Wave Forms

(3) Bolometers are temperature sensitive resistors. Any component having a large temperature coefficient of resistance can be used as a bolometer. However, certain elements have more desirable features than others in power measuring amplifications. A bolometer for RF power measurements should have, in addition to a high temperature coefficient of resistance, a resistance of around 200 ohms and a physical size which is small compared to the wavelengths, also a diameter less than the skin depth of the measured signal. When a bolometer is used to measure microwave power the temperature rise due to the power dissipated in the element changes the resistance of the element. This resistance change can either be measured and calibrated in terms of power, or else an equal resistance change can be effected by DC or audio frequency power. The latter power is then measured by conventional low frequency methods, and its value is equal to the RF power. Bolometer devices include beads of semi-conducting material (thermistors), thin platinum wires (barretters) and metallic or carbon films deposited on glass or mica. A description of the characteristics of these elements, and the manner in which they are used is presented in later lessons.

(4) In the calorimetric technique, power is dissipated on a load and the temperature rise of the load, or of a cooling fluid flowing in or around the load, is measured. This temperature rise can be used to compute the power dissipation in the load to a fair degree of accuracy if sufficient information concerning the heat capacity, heat losses, and other factors are available. However, generally it is easier to calibrate a calorimeter with DC or low frequency power. The temperature rise of the calorimeter can be measured to a high degree of accuracy with thermocouples or bolometers. Therefore, it is not unusual to find calorimetric power meters that incorporate many of the features of the other types of microwave power meters.

(5) The devices previously described all measured power in terms of thermal response. Silenium or germanium crystal rectifiers may be used at microwave frequencies to rectify the RF signal and produce a low frequency or DC output. These microwave crystals may be calibrated with low frequency meters to measure RF power, but as crystals are quite non-linear and extremely sensitive to temperature, humidity, age, and previous operating history indicates that they are not too reliable and frequently require recalibration. However, crystals are useful when only nominal accuracy is needed or when an indication of relative power level rather than an absolute power measurement is desired, for they are rugged and involve a minimum of auxiliary equipment.

c. Methods of Measurement.

(1) In measuring the change in resistance of a bolometric device it is generally practical to place the bolometer in one arm of a Wheatstone bridge. A DC or low frequency bias supply is adjusted to charge the low frequency power in the bolometer. By this means the resistance of the bolometer is varied and the bridge is balanced until

no current flows in the detector arm of the bridge. If RF power is now applied to the bolometer, its resistance changes. The bridge becomes unbalanced and current flows in the detector arm of the bridge. The unbalanced current can be calibrated against low frequency power so that a meter placed in the detector arm of the bridge can have its scale marked to read microwave power directly.

(2) A more precise method is one in which the bridge is always maintained at balance when measurements are made. The bridge is initially balanced with low frequency bias power only, and then the bolometer is exposed to the RF power so that the bridge becomes unbalanced. Sufficient bias power is then removed to rebalance the bridge, and the low frequency power is measured and equated to the incident RF power. The principle advantage of this technique is that it provides a continuous calibration of the bolometer against low frequency power at each measurement. It is not as direct as the unbalanced bridge technique described above but is the more reliable and precise of the two methods because of the self-calibrating feature and because the bolometer is always operated at a constant resistance so that the resistance power curve of the element does not enter into the power determination.

(3) There is a wide variety of commercial bridges available for microwave bolometric power measurements. These units all operate as either balanced or unbalanced bridges although they may have many variations and refinements. Some of these are explained in detail in the following lessons. One important variant of the balanced bridge circuit that bears mention at this time is the self-balancing bridge. This instrument contains a feedback network between the detector and the source of bias power. After the initial calibration adjustment, this type of bridge automatically rebalances itself. This device has the accuracy of the balanced bridge and the ease of operation of the unbalanced bridge incorporated into a direct reading power meter.

(4) In measuring microwave power with a calorimeter, provisions are generally made to permit calibration of the instrument with a DC or 60 Hertz source and meter. Depending upon the design of the device, the calibrating signal is either applied directly to the microwave absorbing element itself, or an auxiliary meter located near the thermocouple junction. The temperature rise of the load is plotted against the known low frequency calibrating power. This curve is then used under RF operating conditions to translate temperature rise into microwave power.

d. Special Equipment for High Power Measurement.

(1) Thermistors, crystals and barretters have relatively low power handling capacities and are generally suitable only for low power level measurements. Calorimeters can be used to measure higher levels of power. However, many attractive features of the low power instruments make it desirable that auxiliary equipment, such as attenuators and power dividers, be employed so that the low power devices can be used for high power measurements.

(2) One component frequently used to extend the range of a low power meter is an attenuator which absorbs and dissipates a large fixed percentage of the applied power. The input power to this attenuator is therefore some known multiple of the output power which is measured by the low level power meter.

(3) A wide variety of devices can be grouped into the class of power dividers. These divert a sample of power from a transmission line into a measuring instrument. The major portion of the power in the transmission line is delivered to a dummy load or the specified transmission line termination. Power dividers have the advantage of permitting measurement of microwave power while it is being delivered to a load. Power dividers include such devices as probes, loops, bifurcations and T and Y junctions. Directional couplers are devices which are designed to produce an output signal proportional to either the incident or the reflected power in a transmission line. Total power can be measured with a bidirectional coupler (which provides two outputs, one proportional to the reflected power and one proportional to the incident power) by subtracting the reflected power from the incident power.

(4) The major advantage of these various power dividers and power reducing units is that their power division ratio can be calibrated at relatively low power levels since the power reducing characteristics are independent of power level.

(5) The description just given indicates that microwave power meters can be additionally classified as to application. Meters of one class terminate the transmission line and absorb all the power being delivered by the generators; the other class of meters removes a small sample of power from a line, and hence permits measurements to be made of power delivered by a generator to a given load under actual operating conditions.

3. Within the calibration system there are numerous standards and accessories used to measure power. Each of these standards will be covered in detail in Lessons Two through Five. The equipment and lesson number is listed in Table 1.

Table 1

EQUIPMENT MODEL NUMBER	LESSON NUMBER
432A Power Meter	2
478A Thermistor Mount	2
486 Thermistor Mount	2
8402B Power Meter Calibrator	3
NBS Type II Power Measurement System	4
MMC MT 9024A Power Standards Set	5

AIPD SUBCOURSE NUMBER MM0474, POWER MEASUREMENTS

EXERCISES FOR LESSON 1

1. Power is divided into three levels, what level would a source with an output of 20 mW be?

   A. Low
   B. Medium
   C. High

2. What component is generally used for high level power measurements?

   A. Calorimeter
   B. Crystal
   C. Barretters

3. Bolometers are devices used to measure power and are

   A. Dissimilar wires connected together.
   B. Thin platinum wires on glass.
   C. Temperature sensitive resistors.

4. What is the advantage of using power dividers when making power measurements?

   A. Allows all power to be delivered to the power meter.
   B. Increases power levels to a load.
   C. Permits measurements of power level while it is being delivered to a load.

5. How can a high level power measurement be made with a low level type power meter?

   A. By the use of calibrated attenuators.
   B. By using special high-power measuring devices and calibrated attenuators.
   C. By measuring the average power of the total.

6. A bolometer device includes beads of semi-conducting material called

   A. Thermistors.
   B. Barretters.
   C. Carbon piles.

7. Crystal rectifiers are used in power measurements because they are rugged and

A. Are not temperature sensitive.
B. Require a minimum of auxiliary equipment.
C. Do not require calibration.

8. How should a bolometric device be placed in a circuit when measuring the change in resistance?

A. In parallel with the measuring device.
B. In series with the measuring device.
C. In one arm of a Wheatstone bridge.

9. Which method of bolometric power measurements is more reliable and precise?

A. Balanced bridge.
B. Unbalanced bridge.
C. Direct.

10. What is the advantage of an unbalanced bridge method of measurement?

A. The bridge is continuously calibrated.
B. Ease of operation.
C. Can be used at DC or low frequency.

LESSON 2. POWER MEASUREMENTS EQUIPMENT, PART I

AIPD Subcourse Number MM0474.....Power Measurements

Lesson Objective.....After studying this lesson you should be able to:

1. State the purpose, characteristics, concepts and operation of bolometers.

2. Describe the purpose, characteristics, operation, block diagram and circuit analysis of power meters and thermistor mounts.

Credit Hours.....Four

TEXT

1. INTRODUCTION.

a. The basic concept of power is the same for microwave as for low frequencies; however, the practical aspects of the two are quite different. For instance, in most circuits, power can be specified and measured in terms of voltage across the circuit and the current flowing through the circuit as a result of such voltage. In microwave, such voltage and current can neither be simply specified, nor can they ordinarily be measured. In microwave, power measurements are often made in the milliwatt region by the bolometric method. In the higher power measurements, the calorimetric methods are used. These concepts find wide application in measurements of attenuation, transmission losses, and other related subjects.

b. The calibrator must have a knowledge of the type of meters used for power measurements. During this lesson we will cover the model 431C and 432A power meters to include the thermistor mounts used with them.

2. MODEL 431C POWER METER.

a. Description.

(1) The Model 431C Power Meter (Figure 1), with temperature-compensated thermistor mounts, measures RF power from 10 microwatts (-20 dBm) to 10 milliwatts (+10 dBm) full scale in the 10 MHz to 40 GHz frequency range. Direct reading accuracy of the instrument is ±1% of

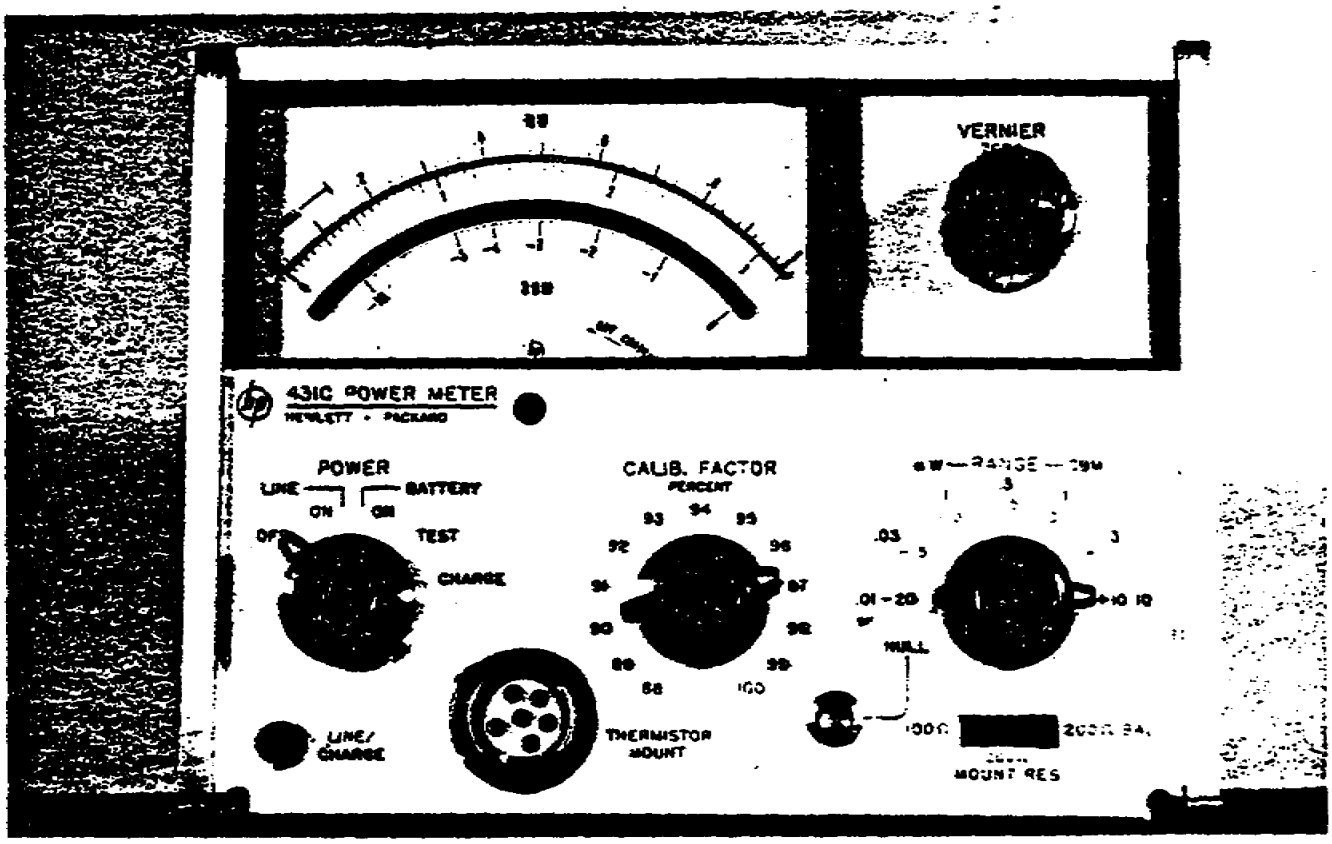


Figure 1. Model 431C power meter.

full scale. By selector switch, the instrument normalizes the power meter reading to compensate for the Calibration Factor of a thermistor mount used for a given measurement. Complete specifications are presented in Table 1.

(2) The Model 431C makes provision for using the DC substitution method of measuring RF power and to assure accuracy of the power meter calibration. Outputs are provided for a digital voltmeter readout, permanent recording of measurements operation of alarm or control system, or to allow the Power Meter to be used in a closed-loop leveling system.

(3) Accessories. Two accessories are supplied with the Model 431C Power Meter: a 7.5 foot (2290 mm) detachable power cable and a 5 foot (1520 mm) cable that connects a thermistor mount to the instrument. Thermistor mounts are available (refer to Table 2) but are not supplied with the power meter.

b. Model 431C, Principles of Operation.

(1) The Model 431C is an automatic self-balancing power-measuring instrument employing dual-bridge circuits. The power meter is designed to operate with temperature-compensated thermistor mounts such as the 8478B and 478A Coaxial and 486A Waveguide series. Power may be

Table 1. Specifications

Power Range: 7 ranges with full-scale readings of 10, 30, 100, and 300 μW. 1, 3, and 10 mW; also calibrated in dBm from −20 dBm to +10 dBm full scale in 5 dB steps.

Accuracy:

+20° C to +35° C:

±1% (100 μW range and above)

±1.5% (30 μW range)

±2% (10 μW range)

0° C to +55° C:

±3% (all ranges)

Calibration Factor Control: 13 position switch normalizes meter reading to account for thermistor mount Calibration Factor (or Effective Efficiency).

Range: 100% to 88% in 1% steps.

Thermistor Mount: External temperature-compensated thermistor mounts required for operation (mdl 478A and 486A series listed in Table 2).

Meter Movement: Taut-band suspension, individually calibrated mirror-backed scales. Milliwatt scale greater than 4.25 in. (108 mm) long.

Zero Carryover: Less than 1% of full scale when zeroes on most sensitive range.

Zero Balance: Continuous control about zero point.

DVM Output: 1.000 V into open circuit corresponds to full scale meter deflection (1.0 on 0-1 scale) ±0.5%; 1 KΩ output impedance, BNC female connector; effect of loading impedance less than 10 MΩ must be accounted for.

Recorder/Leveler Output: With load impedance of 600 ohms or more, output is approximately 1 volt DC at full scale meter deflection. BNC female connector.

DC Calibration Input: Binding posts for calibration of bridge with Mdl 8402B Calibrator or Precise DC standards.

Power: 115 or 230 volts ± 10%, 50 to 400 Hz, 2.5 watts.

Furnished: 5 ft (1520 mm) cable for temperature compensated thermistor mounts; 7.5 ft (2290 mm) power cable, NEMA plug.

Table 2. Model 431C Thermistor Mounts

MODEL		Frequency Range	Operating Resistance (Ohms)
Coaxial	Waveguide		
8478B		10 MHz to 18 GHz	200
478A		10 MHz to 10 GHz	200
	S486A	2.6 to 3.95 GHz	100
	G486A	3.95 to 5.85 GHz	100
	J486A	5.3 to 8.2 GHz	100
	H486A	7.05 to 10.0 GHz	100
	X486A	8.2 to 12.4 GHz	100
	M486A	10.0 to 15.0 GHz	100
	P486A	12.4 to 18.0 GHz	100
	K486A	18.0 to 26.5 GHz	200
	R486A	26.5 to 40.0 GHz	200

measured with these mounts in 50 ohm coaxial systems from 10 MHz to 18 GHz, and in waveguide systems from 2.6 GHz to 40 GHz. Full-scale power ranges are 10 microwatts to 10 milliwatts and -20 dBm to +10 dBma. Extended measurements may be made to 1 microwatt to -30 dBm. The total measurement capacity of the instrument is divided into seven ranges, selectable by a front panel RANGE switch.

(2) ZERO and VERNIER zero-set controls zero the meter. Zero carryover from the most sensitive range to the other six less sensitive ranges is on the particular range to be used. When the RANGE switch is in the NULL position, the meter indicates inherent metering bridge unbalance, and a front panel NULL screwdriver adjustment is provided for initial calibration.

(3) The CALIB FACTOR switch allows the introduction of discrete amounts of compensation for measurement uncertainties related to SWR, and measurement errors caused by substitution error and thermistor mount efficiency. The appropriate selection of a Calibration Factor value permits direct meter reading of the RF power delivered to an impedance equal to the characteristic impedance (Z_O) of the transmission line connecting the thermistor mount to the RF source. Calibration Factor values are determined from the data marked on the label of each 8478B, 478A, or 486A thermistor mount.

(4) The Model 431C has a DC CALIBRATION jack on the rear panel that can be used for DC substitution method of power measurement. DC substitution is an extension of the power measurement technique normally used. Through the use of DC substitution, instrument error can be reduced from a nominal value of ±1% to ±0.16% of reading, or less, depending on the care taken in procedure and accuracy of auxiliary equipment.

(5) The MOUNT RES switch on the front panel permits the use of three types of thermistor mounts with the 431C. Model 486A waveguide mounts can be used by setting the MOUNT RES switch to the 100 ohm or 200 ohm position, depending on the microwave band used (refer to Table 2). The 200 ohm position is used with Model 478A thermistor mounts and the 200 ohm BAL position is used with a balanced thermistor mount such as the 8478B.

CAUTION

To avoid severe damage to the thermistor mount, be careful not to move the MOUNT RES switch while operating the RANGE switch.

(6) Two output BNC type jacks are provided on the rear panel of the instrument, labeled DVM and RECORDER/LEVELER. The DVM jack provides a voltage linearly proportional to the meter current; 1 volt equal to full scale meter deflection. A DVM connected to the 431C must have an input impedance greater than 500 k ohms on the range used. The RECORDER/LEVELER jack furnishes a DC voltage of low source impedance necessary for isolation between a recorder or leveler amplifier and the metering circuit of the power meter. The output voltage is proportional to the power measured and is offset ±40 mV or less from its nominal value, depending on the load impedance. This output voltage allows the Model 431C to be used in a number of additional applications.

c. Controls, Connectors, and Indicators.

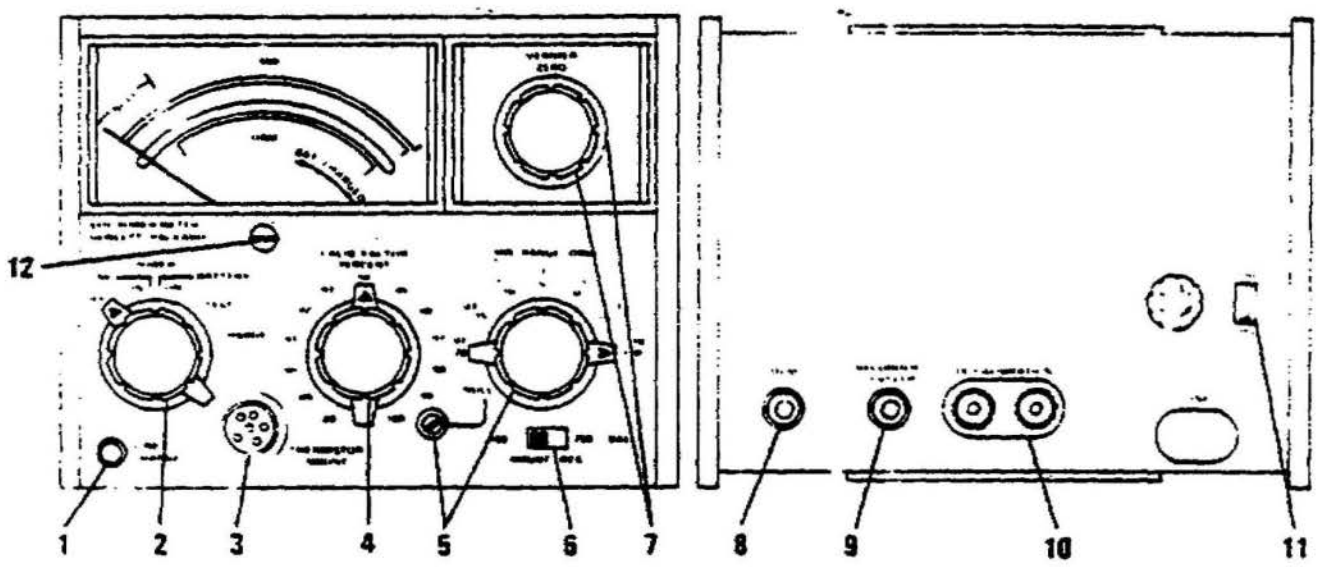
The front and rear panel controls, connectors, and indicators are explained in Figure 2. The descriptions are keyed to the corresponding items which are indicated on the figure. Further information regarding the various settings and uses of the controls, connectors, and indicators is included in the applicable procedures of this lesson.

d. Operating Instructions.

Figure 3, Turn-On and Nulling Procedures, present step-by-step instructions for operating the Model 431C. Steps are numbered to correspond with the appropriate control, connector, or indicator on the power meter.

e. Major Sources of Error in Microwave Power Measurement.

(1) A number of factors affect the overall accuracy of power measurement. Major sources of error are presented in the following paragraphs to show the cause and effect of each error. Particular corrections or special measurement techniques can be determined and applied to improve overall measurement accuracy. The following are the major sources of error to consider: 1) mismatch error, 2) RF losses, 3) DC-to-microwave substitution error, 4) thermoelectric effect error, and 5) instrumentation error.



1. LINE CHARGE. Lamp lights when the POWER switch is in the LINE ON or BATTERY CHARGE position.

2. POWER. Determines connections to primary power sources and the battery charging circuit.

   LINE OFF: Instrument off.

   LINE ON: Instrument on. Trickle charge applied to battery.

   BATTERY ON: Instrument on, battery powered.

   BATTERY TEST: Meter indicates battery charge.

   BATTERY CHARGE: Instrument off. Trickle charge applied to battery.

3. THERMISTOR MOUNT. Accepts the thermistor mount cable.

4. CALIB FACTOR. Switch compensates for the Calibration Factor of the thermistor mount. Calibration Factor values from 88% to 100% may be set in 1% steps.

5. RANGE. Sets power range; also includes a NULL position which, in conjunction with the adjacent null screwdriver adjustment, ensures that the metering bridge is reactively balanced.

6. MOUNT RES. A three position slide switch which sets the power meter to accommodate thermistor mounts of 100 ohm, 200 ohm and 200 ohm balanced operating resistances.

7. ZERO and VERNIER. Sets the meter pointer over the zero mark. The VERNIER control is a fine adjustment of the ZERO control setting.

8. DVM. A BNC type jack providing an output voltage linearly proportional to the meter indication. A DC voltmeter with an input impedance less than 10 M ohms is required to minimize introduction of measurement error.

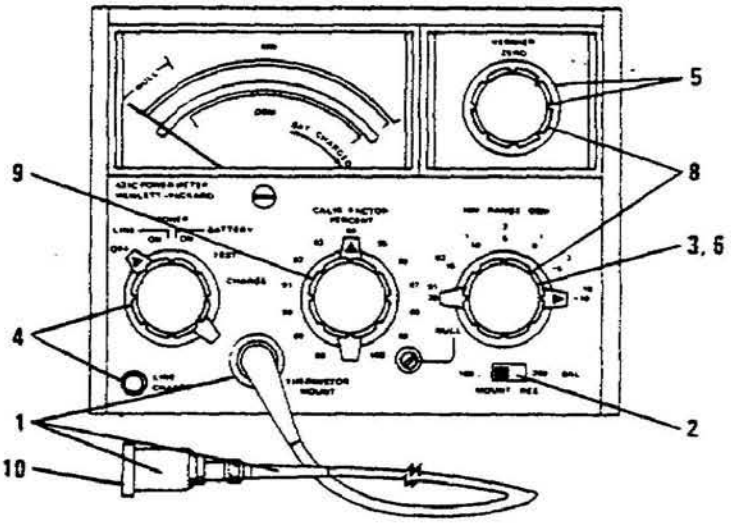
9. RECORDER LEVELER. A BNC type jack providing a DC voltage of low source impedance for a recorder or leveler amplifier.

10. DC CALIBRATION. This connector permits a DC input for power meter calibration and DC substitution method of power measurement.

11. LINE VOLTAGE. Selects 115- or 230-volt line operation.

12. Mechanically zeroes meter.

Figure 2. Front and Rear Panel Controls, Connectors, and Indicators.



1. Connect thermistor mount and cable to THERMISTOR MOUNT connector. Refer to Table 1-2 for recommended thermistor mounts and their frequency ranges.

   Meter Mechanical Zero:

   a. With instrument turned off, rotate meter adjustment screw clockwise until pointer approaches zero mark from the left.

   b. Continue rotating clockwise until pointer coincides with zero mark. If pointer overshoots, continue rotating adjustment screw clockwise until pointer once again approaches zero mark from the left.

   c. Rotate adjustment screw about three degrees counterclockwise to disengage screw adjustment from meter suspension.

Note

When using an hp Model 478A or other 200 ohm unbalanced coaxial thermistor mount, the power meter should be zeroed and nulled with the RF power source be zeroed and nulled with the RF power source turned off and connected to the thermistor mount. If the RF power source cannot be turned off, the power meter must be zeroed and nulled while the RF input connection of the thermistor mount is terminated in the same 10 kHz impedance as that presented by the power source (short, open, or 50 ohm). These precautions are not necessary when waveguide mounts such as the hp Model 486A series or balanced 200 ohm coaxial mounts are used.

2. Set MOUNT RES switch to correspond to the operating resistance and type of thermistor mount used.

CAUTION

To avoid severe damage to the thermistor mount, be careful not to move the MOUNT RES switch while operating the RANGE switch.

3. Set RANGE to .01 mW.

4. Set POWER to LINE ON. If instrument is to be battery operated, rotate POWER to BATTERY ON.

5. Adjust ZERO control for 25% to 75% of full scale on meter.

6. Rotate RANGE switch to NULL and adjust NULL screwdriver adjustment (adjacent to NULL on RANGE switch) for minimum reading.

7. Repeat steps 5 and 6 until NULL reading is within NULL region on the meter.

8. Set RANGE switch to the power range to be used and zero-set the meter with ZERO and VERNIER controls.

Note

Range-to-range zero carryover is less than ±1.0% if the meter has been properly adjusted mechanically (Step 1 above) and the instrument has been properly zero-set electrically on its most senstive range. For maximum accuracy, zero-set the power meter on the range to be used.

9. Set CALIB FACTOR switch to correspond with Calibration Factor imprinted on hp thermistor mount label.

10. Apply RF power at the thermistor mount. Power is indicated on the meter directly in mW or dBm.

Figure 3. Turn On and Nulling Procedure.

(2) Mismatch Error. The following discussion uses the terms conjugate power, Z_O available power, conjugate match and mismatch, and Z_O match and mismatch. These basic terms are defined as follows:

Conjugate power is the maximum available power. It is dependent on a conjugate match condition in which the impedance seen looking toward the thermistor mount is the complex conjugate of the impedance seen looking toward the RF source. A special case of this maximum power transfer is when both the RE source and the thermistor mount have the same impedance as the transmission line.

Z_O available power is the power a source will deliver to a Z_O load. It is dependent on a Z_O match condition in which the impedance seen looking into a transmission line is equal to the characteristic impedance of the line.

(3) In a practical measurement situation, both the source and thermistor mount have SWR, and the source is seldom matched to the thermistor mount without the use of a tuner.

The amount of mismatch loss in any measurement depends on the total SWR present. The impedance that the source sees is determined by the actual thermistor mount impedance, the electrical length of the line, and the characteristics impedance of the line, Z_O.

(4) In general, neither the source nor the thermistor mount has Z_O impedance, and the actual impedances are known only as reflection coefficients, mismatch losses or SWR. These forms of information lack phase information data. As a result, the power delivered to the thermistor mount and hence the mismatch loss can only be described as being somewhere between two limits. The uncertainty of power measurement due to mismatch loss increases with SWR. Limits of mismatch loss are generally determined by means of a chart such as the Mismatch Loss Limits charts in Figures 4 and 5.

(5) An example may explain how imperfect match affects the uncertainty of power measurement. A typical Z_O available power measurement situation can involve a source with an SWR of 1.7 (p_s = 0.26) and a thermistor mount with an SWR of 1.3 (p_m = 0.13). Figure 6 shows a plot of power levels and mismatch power uncertainties that result from source and thermistor mount mismatch. The source Z_O mismatch results in a power loss of -0.29 dB from the maximum power that would be delivered by the source to a conjugate match. The power level that results from this loss is the Z_O available power. The thermistor mount Z_O mismatch causes an additional power loss of -0.07 dB. However, on the thermistor mount Z_O mismatch loss is an uncertainty resulting from the unknown phase

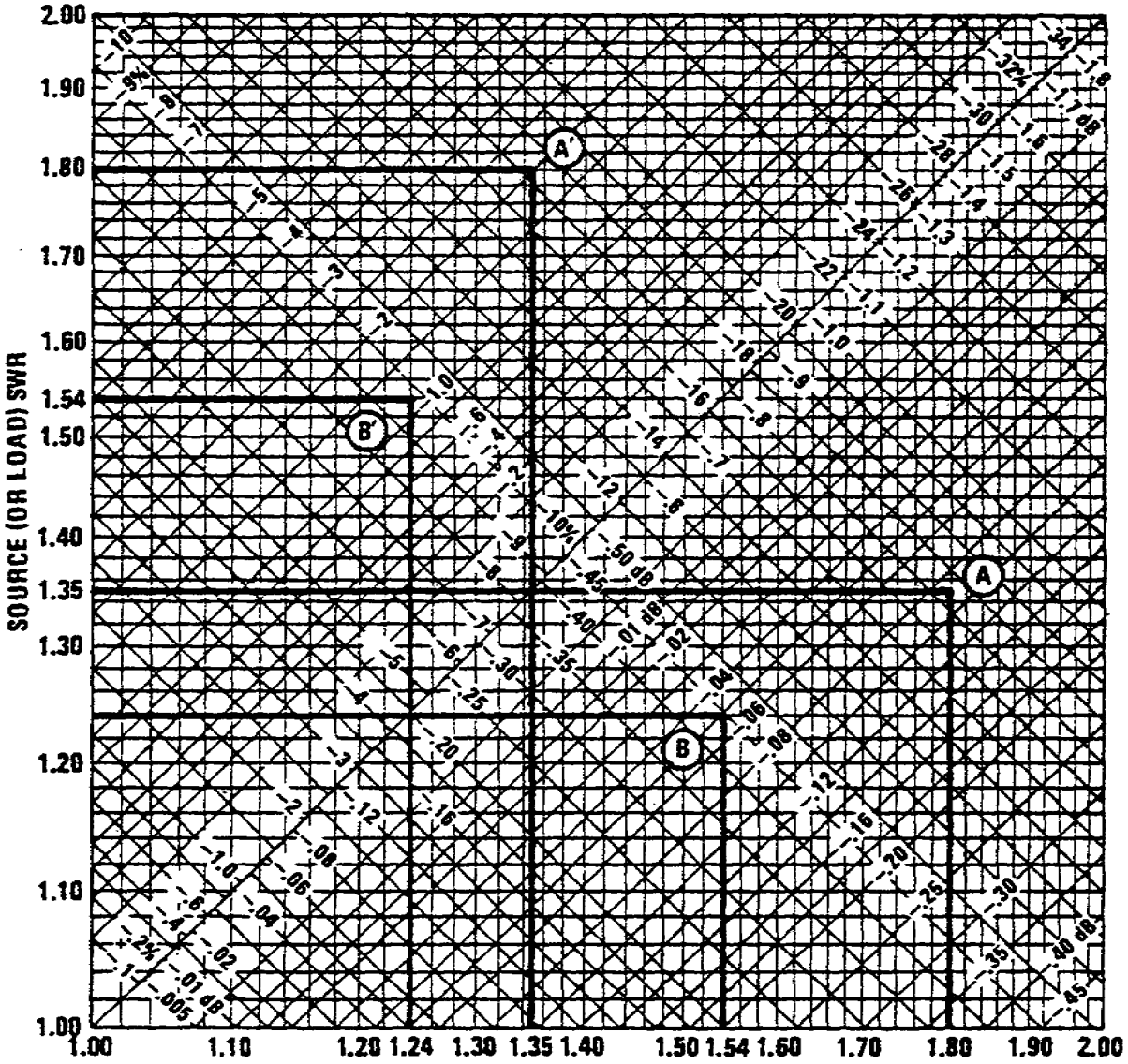


Figure 4. Conjugate Mismatch-Loss Chart.

relationships between the impedances of the source and thermistor mount. This uncertainty is +0.30 dB to -0.28 dB and can be determined from the Mismatch Loss Limits charts in Figures 4 and 5.

(6) The result of the total mismatch loss uncertainty on the Z_O available power leave is determined by algebraically adding the thermistor mount loss to the uncertainty caused by source and thermistor mount Z_O mismatch SWR. Thus, the Z_O available power uncertainty is (-0.07 dB) + (+0.30 dB), and (-0.07 dB) + (-0.28 dB), equal to a range of +0.23 dB to -0.35 dB to +5.5% to -8.2%. The power delivered by the

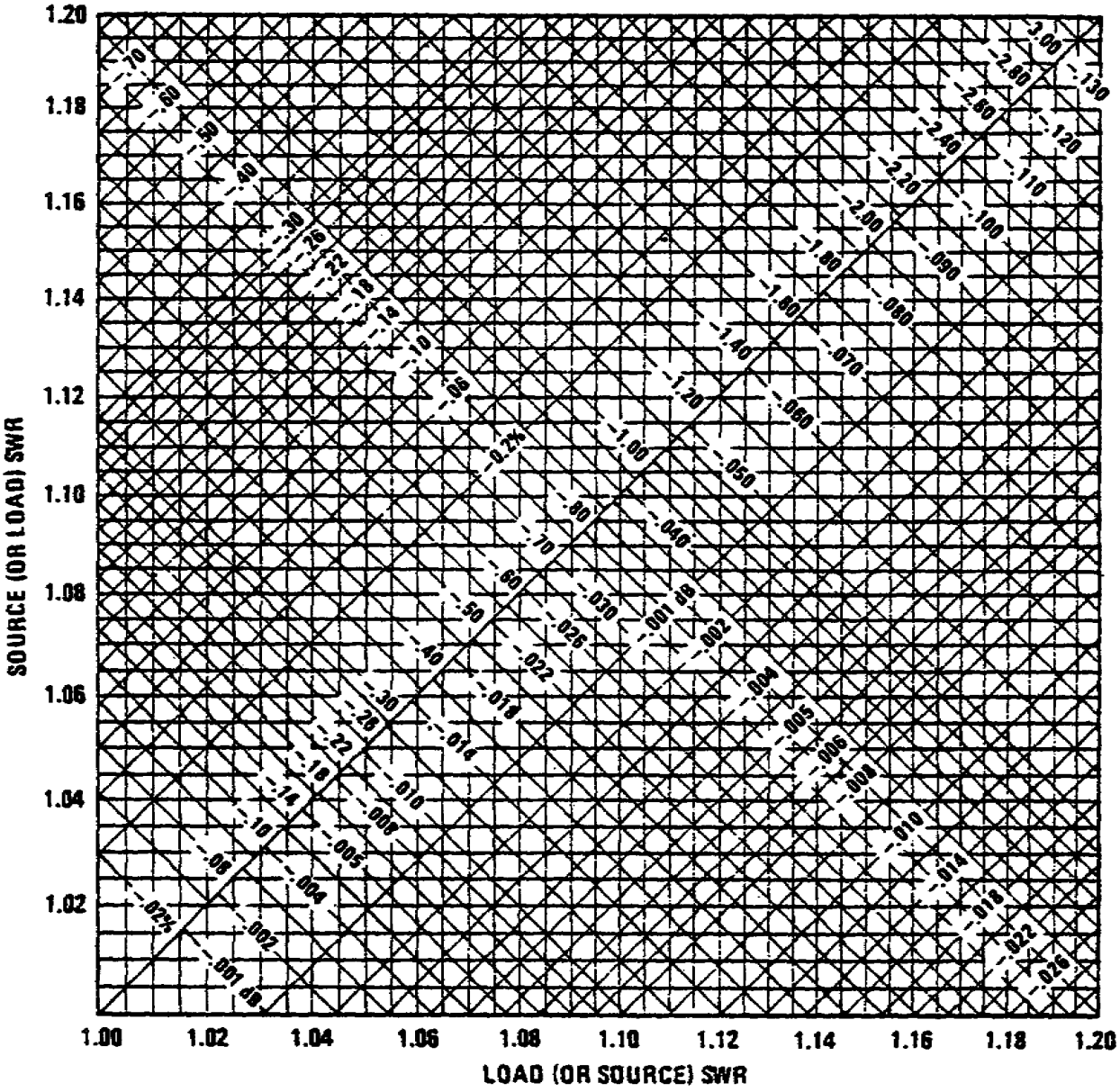


Figure 5. Expanded Conjugate Mismatch-Loss Chart Covering SWR's from 1.00 to 1.20. Chart is read in same manner as Figure 4.

source to a Z_O load, with source and thermistor mount mismatch as in this example, would be somewhere between 0.23 dB (5.5%) below the maximum power and 0.35 dB (8.2%) above the minimum power actually entering the thermistor mount.

(7) Power measurement uncertainty caused by mismatch loss is one source of error to consider when measuring Z_O available power without a tuner.

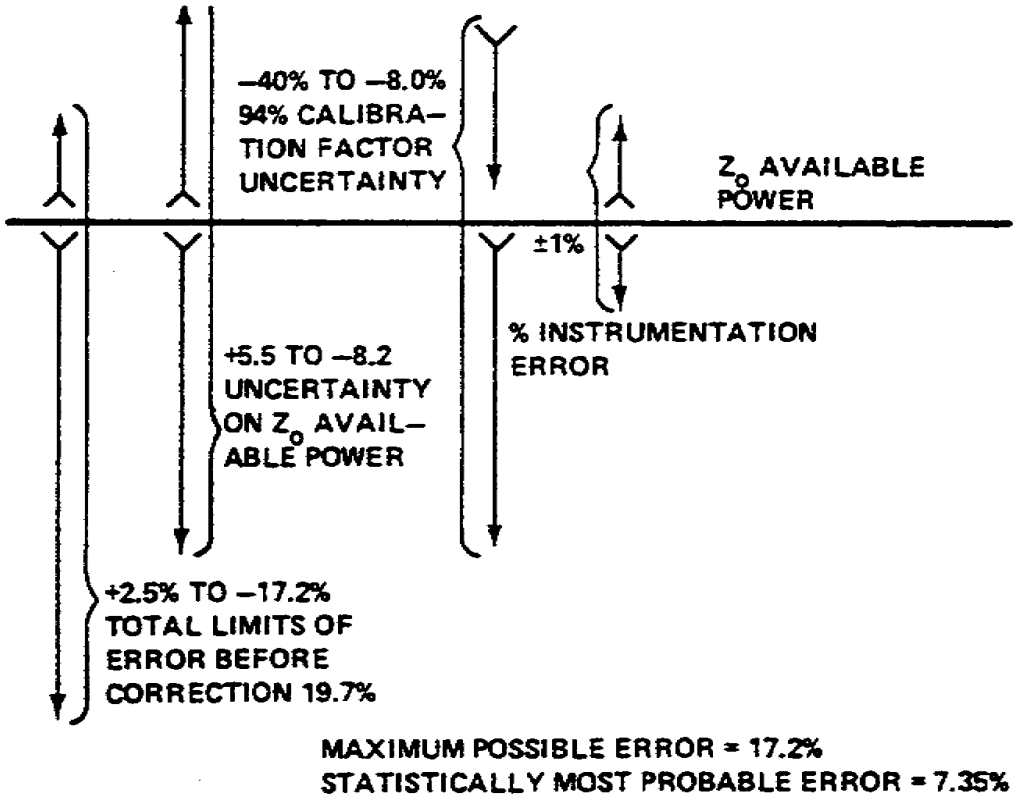


Figure 6. Limits of Error Before Correction.

(8) RF Losses and DC-to-Microwave Substitution Error. RF losses account for the power entering the thermistor mount but not dissipated in the detection thermistor element. Such losses may be in the walls of a waveguide mount, the center conductor of a coaxial mount, capacitor dielectric, poor connections within the mount, or due to radiation. DC-to-microwave substitution error is caused by the difference in heating effects of the substituted audio bias of DC power and the RF power. RF losses and DC-to-microwave substitution error are generally combined for the simplicity of analysis.

(9) Thermoelectric Effect Error. A mild thermocouple voltage exists at each point of contact where the connecting wires join to the thermistor elements. Each thermocouple creates a DC voltage. Thus, two thermocouple voltages of opposite relative polarity are formed, one at each junction to each thermistor element.

(10) Ideally, each thermocouple voltage would be equal in magnitude so that they cancel with no resultant effect on the accuracy of power measurement. In practice, however, each point of contact does not have identical thermocouple characteristics, and in addition, the temperatures at each junction may not be the same. These differences cause an incomplete cancellation of the thermoelectric voltages, resulting in a voltage that causes a thermoelectric effect error. The magnitude of the error is important when making DC substitution measurements on the 0.1 mW; 0.03 mW, and 0.01 mW ranges. On other

ranges, the effect is negligible. For most mounts, maximum error introduced by thermoelectric effect is about 0.3 μW and is typically 0.1 μW on the 0.01 mW range.

(11) Instrumentation Error. The degree of inability of the instrument to measure the true substitution audio bias or DC power supplied to the thermistor mount is called power meter accuracy or instrumentation error. Instrumentation error of the Model 431C is ±2% of full scale, +20°C to +35°C. Instrumentation error can be reduced to ±0.16% of reading, or less, by using DC substitution.

f. Calibration Factor and Effective Efficiency.

(1) Calibration Factor and Effective Efficiency are two power ratios used as correction factors to improve overall accuracy of microwave power measurements. The ratios are used under different measurement conditions. Calibration Factor is used when the thermistor mount is coupled to the RF source without a tuner. Calibration Factor corrects for both SWR and inefficiency of the thermistor mount. Effective Efficiency corrects only for the inefficiency of the thermistor mount.

(2) Each thermistor mount has a particular impedance. This impedance, and hence the mount SWR, remain constant over the major portion of the microwave band for which the mount is designed to operate. For most thermistor mounts this constant SWR is low; thus the mismatch uncertainty is small. Since the mount impedance and corresponding SWR deviate significantly only at the high and low ends of a microwave band, it is generally unnecessary to use a tuner. However, a tuner or other effective means of reducing mismatch error is recommended when the source SWR is high or when high accuracy is required. To minimize mismatch between the source and the thermistor mount without the use of a toner, a low SWR precision attenuator can be inserted in the transmission line to isolate the thermistor mount from the source. Since a tuner is not often used, Calibration Factor is a more practical term than Effective Efficiency.

(3) Calibration Factor. Calibration Factor is the ratio of substituted audio or DC power in the thermistor mount to the microwave RF power incident upon the mount.

$$\text{Calibration Factor} = \frac{P_{DC}\ \text{Substituted}}{P_{\mu}\ \text{Wave Incident}}$$

Calibration Factor is a figure of merit assigned to a thermistor mount to correct for the following sources of error: 1) RF reflected by the mount due to mismatch, 2) RF loss caused by absorption within the mount but not in the thermistor element, and 3) DC-to-microwave substitution error.

(4) The CALIB FACTOR switch on the front panel allows rapid power measurements to be made with improved accuracy. The switch is set to the Calibration Factor value, appropriate to the frequency of measurement, imprinted on the thermistor mount label. With the proper setting, the 431C compensates for the Calibration Factor of the thermistor mount.

(5) Calibration Factor is applied as a correction factor to all measurements made without a tuner. Under this condition, the power indicated is the power that would be delivered by the source to a load impedance equal to Z_O. This measured power is called Z_O available power.

(6) Calibration Factor correction ensures that a power measurement uncertainty range is centered on the Z_O available power level instead of on the power delivered to the thermistor mount impedance. Total measurement uncertainty limits for a given power measurement using Calibration Factor are the sum of the uncertainties contributed by: 1) Mismatch loss, 2) Calibration Factor uncertainty, and 3) Instrumentation error. Before correction, the maximum possible error is 17.2% and the statistically most probable error is -7.35%.

(7) Figure 7 shows the total power measurement uncertainty after Calibration Factor correction. Note that the range of uncertainty, 19.7%, is the same as it was before correction. However, the measurement uncertainty range has shifted, and is now more symmetrical about the Z_O available power-level.* The total uncertainty after correction is the algebraic sum of the instrumentation error (±1%), the accuracy to which the Calibration Factor is determined (±2%), and the uncertainty on the power actually entering the thermistor mount. After correction, the power measurement uncertainty on the Z_O available power is +10.2% to -9.5%. The maximum possible error is 10.2% (was 17.2%) and the statistically most probable error is +0.35% (was -7.35%). This is a typical example showing how the use of Calibration Factor correction to a measurement to Z_O available power not only reduces the maximum possible error, but more importantly, the magnitude of the statistically most probable error is reduced to very near the Z_O available power level.

*The relationship between indicated power on the 431C and the Z_O available power is given by the following equation:

$$P_o = \frac{\text{P indicated } (1 \pm P_s P_m)^2}{\text{Calibration Factor}}$$

where:

P_o = Z_o available power

P_s = source reflection coefficient

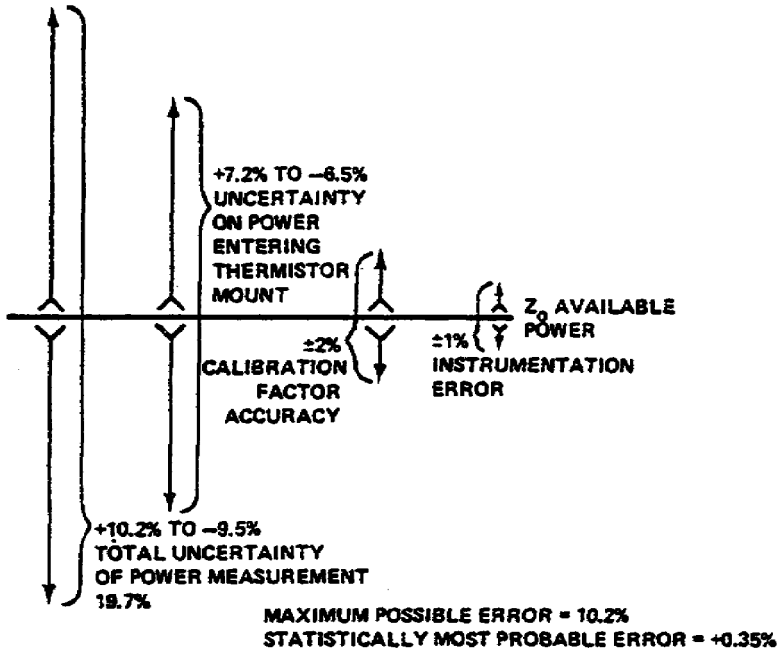


Figure 7. Total Uncertainty After Correction.

P_m = thermistor mount reflection coefficient

$$p = \frac{SWR - 1}{SWR + 1}$$

(8) Effective Efficiency. Effective Efficiency is the ratio of substituted audio or DC power in the thermistor mount to the microwave RF power dissipated within the mount.

$$\text{Effective Efficiency} = \frac{P_{DC}\ \text{Substituted}}{P_{\mu wave}\ \text{Dissipated}}$$

This power ratio corrects for RF losses and DC-to-microwave substitution error in the thermistor mount. It is largely independent of the level of input RF power. When a tuner is used to present either a conjugate or Z_O match to the microwave RF source, Effective Efficiency is to be applied as a correction factor to the power measurement because all of the power incident upon the mount is absorbed in the mount. The use of a tuner and application of Effective Efficiency is the most accurate method of measuring power since source and thus, measurement uncertainty due to mismatch is eliminated. Tuner loss will generally be small.

However, its effects on power measurement can be corrected for by dividing the indicated power by the tuner-loss ratio, power out/power in.

(9) Effective Efficiency can be applied as a correction factor to both conjugate available and Z_O available power measurements. The CALIB FACTOR switch is set to the Effective Efficiency value, appropriate to the frequency under test, imprinted on the thermistor mount label. The type of application of the tuner determines if the power measured is conjugate available or Z_O available.

(10) Conjugate available power is measured when the system consisting of the RF source, transmission line, tuner and thermistor mount is tuned for a maximum power level on the 431C. In this application, the system-mount combination presents a conjugate match to the source. The power measured is the actual power that would be delivered by the source to a conjugate load.

(11) Z_O available power is measured when a tuner-thermistor mount combination is tuned for minimum reflection caused by mount mismatch at the frequency of interest. The tuner adjustment is made on a reflectometer or slotted line system, external to the measurement system used for power measurement. After the tuner adjustment, the tuner-thermistor mount combination is connected to the transmission line and RF source on which a power measurement is made.

g. High Accuracy of Power Measurement Using DC Substitution.

The instrumentation source of error can be reduced by using DC substitution. With precision instruments used in a DC substitution set up, and careful procedure, instrument error can be reduced from ±1% of full scale to ±0.16% of reading, or less. The technique involves: 1) applying the RF power to be measured to the thermistor mount and noting the power meter reading, 2) removing the RF power from the thermistor mount and substituting a DC current from an external DC power source to precisely duplicate the meter reading obtained in step 1, and 3) calculating the power from the substituted DC current and thermistor operating resistance.

h. Block Diagram.

(1) The Model 431C Power Meter measures microwave power indirectly using two bridge circuits (refer to Figure 8). The detection bridge incorporates a 10 kHz oscillator whose amplitude is determined by the amount of microwave power heating the thermistors in that bridge.

(2) The compensation and metering bridge contains thermistors that are immersed in the same thermal environment as those of the detection bridge. It is fed the same 10 kHz bias current that flows in the detection bridge.

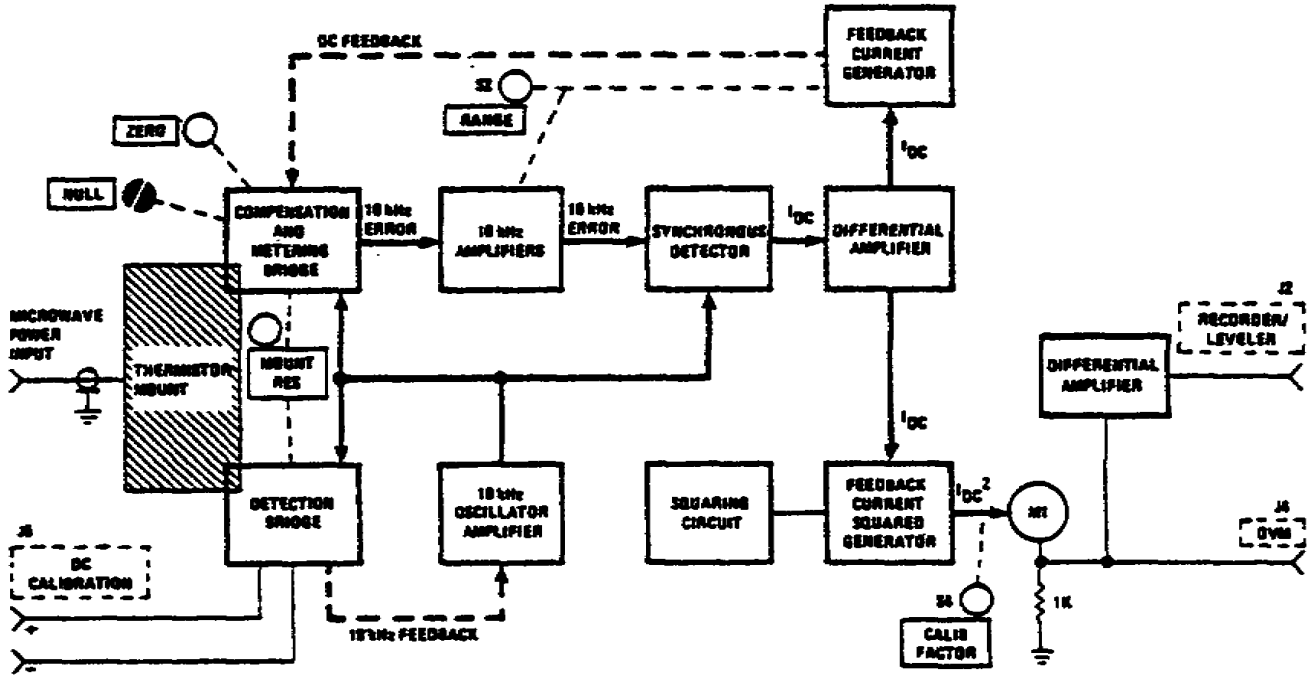


Figure 8. Block Diagram, Model 431C.

(3) Unbalance in the metering bridge produces 10 kHz error signal; this, plus 10 kHz bias taken directly from the oscillator-amplifier, are mixed in the synchronous detector to produce an error-proportional direct current. Fed back to the metering bridge, DC power substitutes for the 10 kHz power in heating the thermistors and drives the bridge toward balance.

(4) The DC output of the synchronous detector also operates the meter circuit.

i. Circuit Description.

(1) RF Detection Bridge (Figure 9). The RF detection bridge and the 10 kHz oscillator-amplifier are connected in closed loop (the detection loop) which provides positive feedback to cause oscillation. The RF bridge includes thermistor element R_d, the secondaries of transformer A1T2, capacitance C_a and C_b, and the resistive arm consisting of A1R10 and parallel resistors selected by the MOUNT RES switch.

(2) When the power meter is off, thermistor R_d is at room temperature and its resistance is about 1500 ohms. The bridge is unbalanced. When the power meter is turned on, a large error signal is initially applied to the bridge. As this signal heats R_d, its resistance decreases toward the operating value of 100 or 200 ohms and the RF bridge approaches balance. The 10 KHz feedback diminishes until there is just sufficient power dissipated in the thermistors to maintain them at the operating resistance.

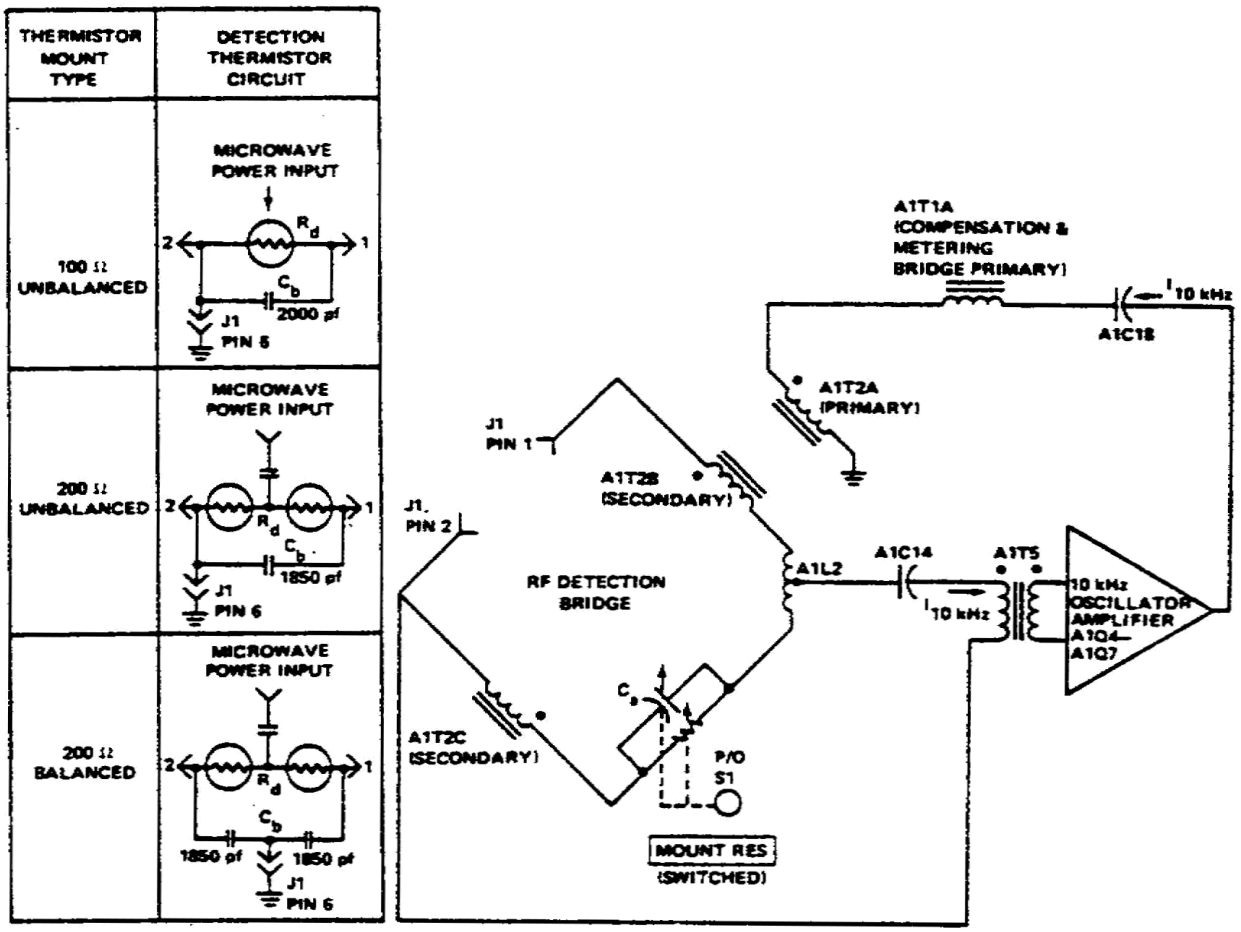


Figure 9. RF Detection Bridge.

(3) Microwave power, applied to the thermistors, heats them further; this decreases the error signal, reducing 10 kHz power just enough to balance out the microwave power.

(4) The MOUNT RES switch, S1, changes the resistance arm of the RF detection bridge so that the bridge will function with either a 100 ohm unbalanced, 200 ohm unbalanced or 200 ohm balanced thermistor mount. The 200 ohm BAL position allows the power meter to be operated with balanced thermistor mounts. When the MOUNT RES switch is in this position two equal capacitors are connected in series across the thermistors with their common point grounded. Identical capacitors are connected in a similar manner across A1R10 in the resistance arm of the RF detection bridge. All other grounds are removed from the bridge so that the

entire bridge is floating with respect to DC ground. This circuit configuration provides a virtual 10 kHz ground at, the RF input point to the balanced thermistor mount.

j. Compensation and Metering Bridge Circuit.

(1) A simplified schematic diagram of the compensation and metering bridge circuit is shown in Figure 10. Operation of the metering bridge circuit is similar to the RF detection bridge circuit. It uses the same principle of self-balancing through a closed loop (metering loop). The major difference is that DC rather than 10 kHz power is used to re-balance the loop. The resistant balance point is adjusted by the ZERO and VERNIER controls which constitute one arm of the bridge. The MOUNT RES switch, which is mechanically linked to both the RF bridge and metering bridge, changes metering bridge reference resistance from 100 to 200 ohms. When the MOUNT RES switch is in the 200 ohm or 200 ohm BAL position some of the feedback current is shunted to ground through R1. This maintains the I^2R function constant when mount resistance is changed from 100 to 200 ohms. The switch also adds the necessary reactance for each position.

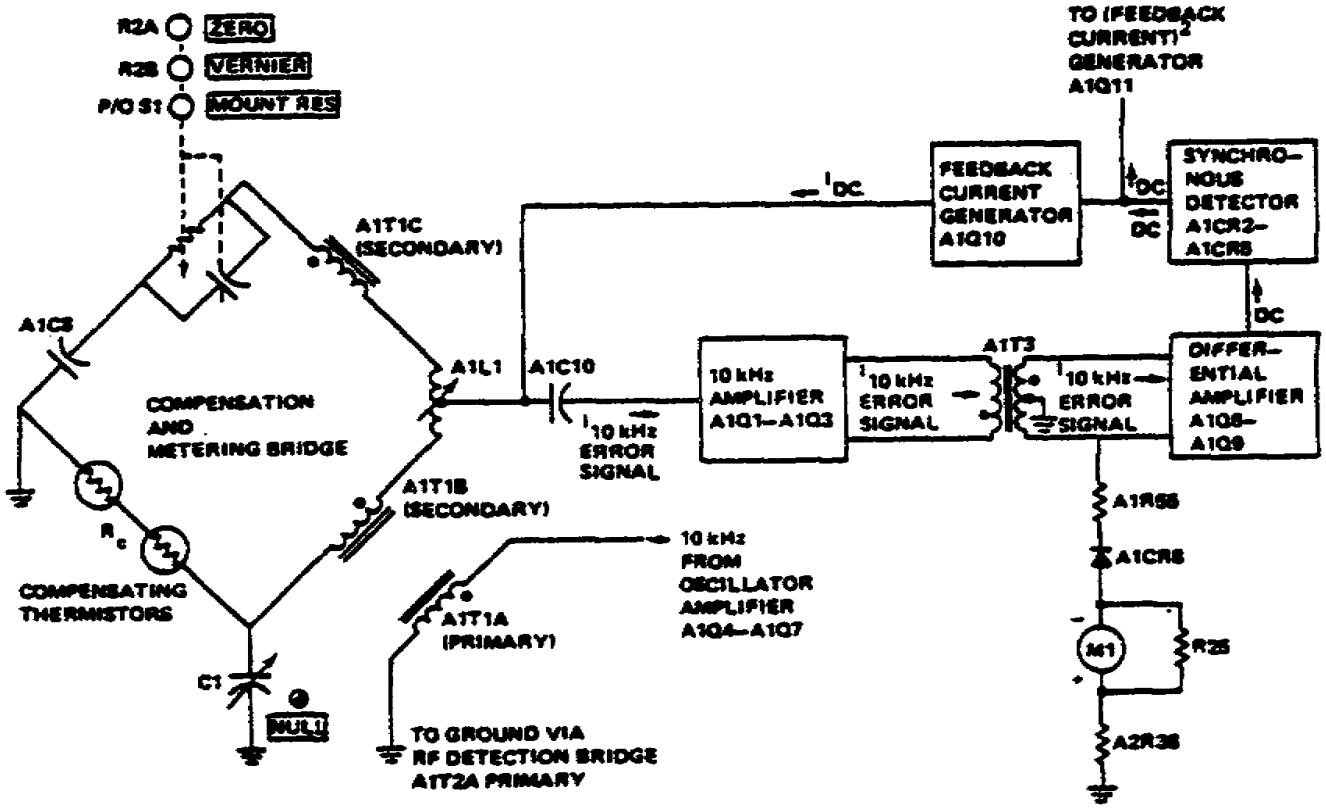


Figure 10. Compensation and Metering Bridge.

(2) The same 10 kHz power change produced in the RF bridge by RF power also affects the metering bridge through the series connection of A1T1 and A1T2 primaries. Although this change of 10 kHz power has equal effect on both the RF and metering bridges, it is initiated by the RF bridge circuit alone. The metering bridge cannot control 10 kHz bias power, but the 10 kHz bias power does affect the metering circuit. Once a change in the 10 kHz bias power has affected (unbalanced) the metering bridge, a separate, closed DC feedback loop (metering loop) re-establishes equilibrium in the metering circuit.

(3) Variations in the 10 kHz bias level, initiated in the RF bridge circuit, cause proportional unbalance of the metering bridge, and there is a change in the 10 kHz error signal (I_{10}kHz) applied to the 10 kHz tuned amplifiers in the metering loop. These error signal variations are amplified by three 10 kHz amplifiers, and rectified by the synchronous detector. From the synchronous detector the DC equivalent (I_{DC}) of the 10 kHz signal is returned to the metering bridge, and is monitored by the metering circuit to be indicated by the meter. This DC feedback to the metering bridge acts to return the bridge to its normal, near-balance condition.

(4) The reactive components of the metering bridge are balanced with variable capacitor C1 and inductor A1Ll. Null adjust, C1, is an operation adjustment and L1 is a maintenance adjustment. Null adjust, C1, is adjusted with the RANGE switch in the NULL position. The 10 kHz signal is taken at the synchronous detector, rectified by A1CR8, and read on the meter. The rectified signal contains both reactive and resistive voltage components of the bridge unbalance.

k. Synchronous Detector.

(1) A simplified schematic of the synchronous detector is shown in Figure 11. The synchronous detector converts the 10 kHz error signal from the metering bridge to a varying DC signal. The detector is a bridge rectifier which has a rectifier in series with a linearizing resistance in each of its arms. Two 10 kHz voltages, designated E3 and E4 in Figure 11, are applied to the bridge; 1) voltage E3, induced in the secondary of A1T3, is proportional to the metering bridge error signal and is incoming from 10 kHz tuned amplifier Q3; 2) voltage E4, induced in the secondary A1T4, is proportional to a voltage supplied by the 10 kHz oscillator-amplifier. Voltage E4 is much larger than voltage E3 and switches appropriate diodes in and out of the circuit to rectify voltage E3. Section (a) of Figure 11 shows the current path through diodes A1CR2 and A1CR3 for a negative-going signal. The rectified output is taken at the center taps of transformers A1T3 and A1T4.

(2) The synchronous detector operates in the following manner. When the left side of A1T4 is positive with respect to the right side, as in Figure 11(a), diodes A1CR4 and A1CR5 conduct while diodes A1CR2 and A1CR3 are biased off. With the polarities reversed, as in

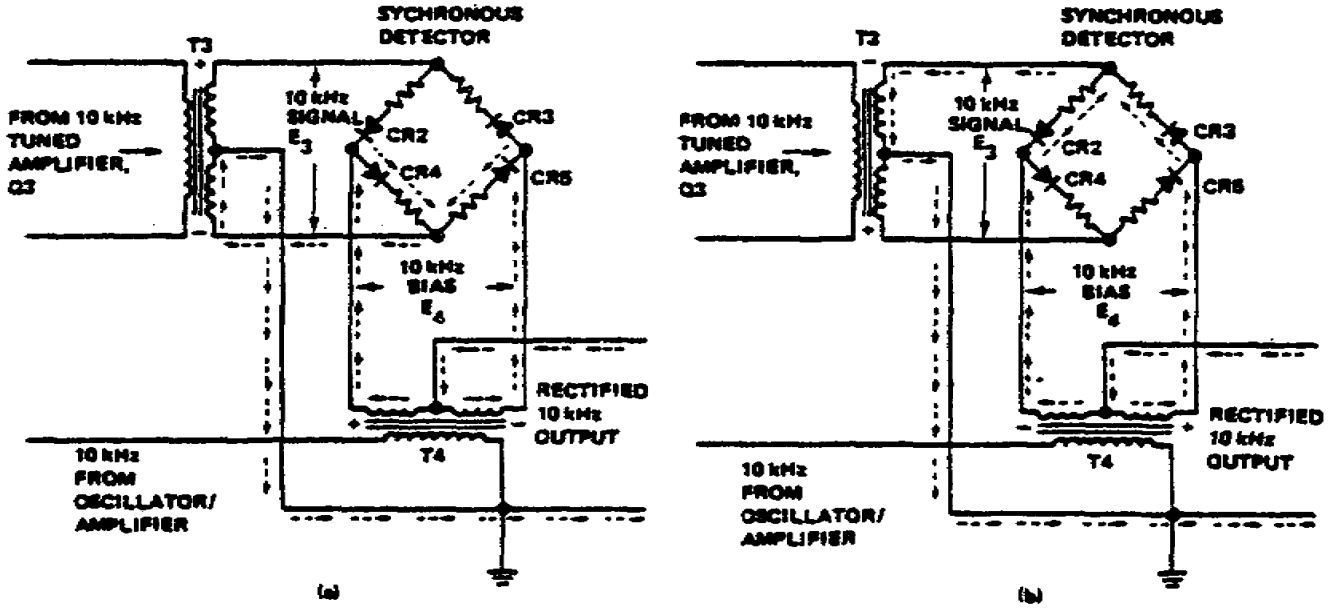


Figure 11. Synchronous Detector.

Figure 11(b), the diodes A1CR4 and A1CR5 are biased off. The resultant output is a pulsating DC signal equivalent to the applied 10 kHz error signal. The pulsating DC signal is filtered and applied to differential amplifier A1Q8 and A1Q9.

(3) The operation of the synchronous detector requires an in-phase relationship between E3 and E4. The amplitude of E4 must be greater than that of E3 at all times.

l. Feedback Differential Amplifier.

A simplified schematic diagram of the feedback differential amplifier is shown in Figure 12. The feedback circuit differential amplifier comprises A1Q8, A1Q9, and associated circuitry. Pulsating DC from the synchronous detector is filtered by A1C19, A1C20, and A1R35, amplified by A1Q8 and fed to both the feedback current-squared generator A1Q11, and the feedback current generator A1Q10. Temperature compensation and low emitter circuit resistance for A1Q10 and A1Q11 from excessive reverse bias when A1Q8 is not conducting.

m. Feedback Current Generator.

A simplified schematic diagram of the feedback current generator is shown in Figure 13. The DC signal from the differential amplifier is applied to the feedback current generator A1Q10. A1Q10 serves two functions: 1) it completes the metering loop to the metering bridge, and 2) it operates in conjunction with the first 10 kHz amplifier, A1Q1,

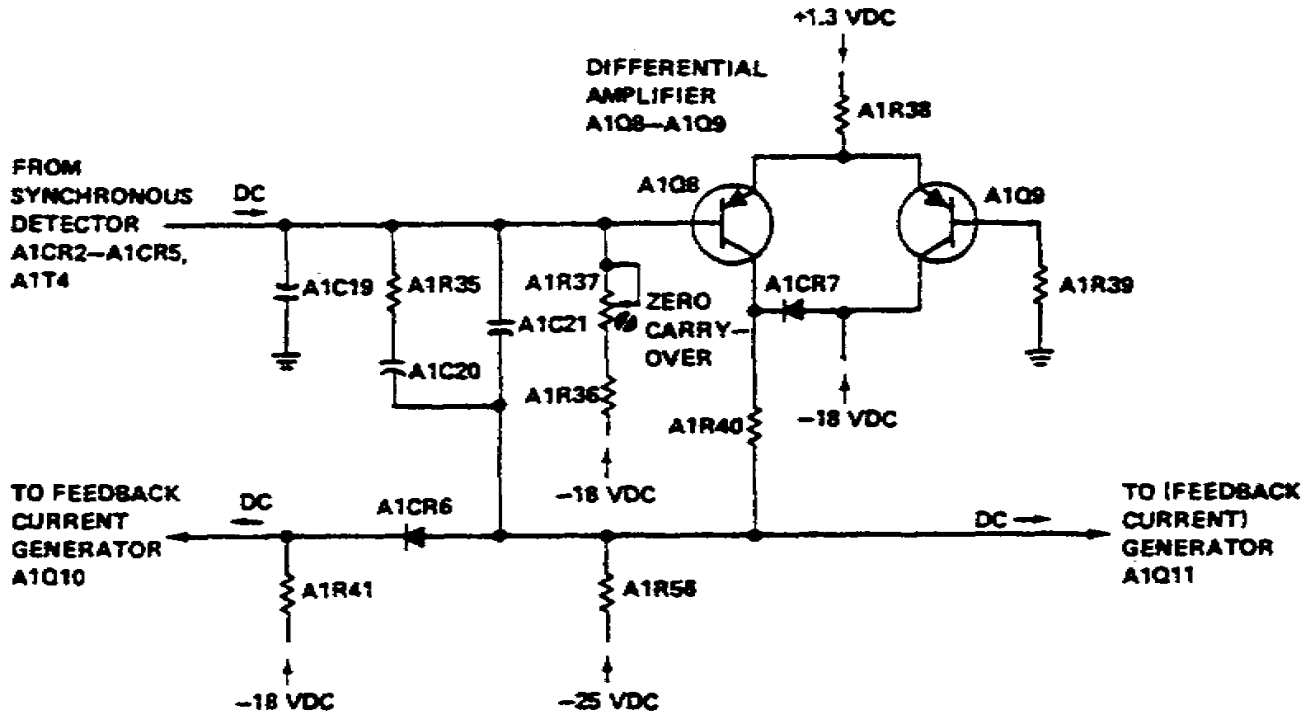


Figure 12. Feedback Differential Amplifier.

and the RANGE switch to change metering loop gain so that the meter will read full scale for each power range. Potentiometer adjustments are provided to accurately set the calibration on each range. Diode A1CR6 provides temperature compensation for A1Q10.

n. Meter Circuit.

A simplified schematic diagram of the meter circuit is shown in Figure 14. The meter circuit includes feedback current-squared generator A1Q11, a squaring circuit, the meter, RECORDER/LEVELER and DVM jacks, J2 and J4. The purpose of the meter circuit is to convert a linear voltage function, proportional to the square root of applied power, to a square function so that power may be indicated on a linear meter scale. The linear voltage function is applied to the base of A1Q11 and is converted to a square law function by the squaring circuit in series with A1Q11 emitter.

o. Metering Circuit Differential Amplifier.

(1) The metering circuit RECORDER/LEVELER output is a voltage of low source impedance necessary for isolation between a recorder or leveler amplifier and the metering circuit of the power meter. The isolation circuit comprises the differential amplifier A2Q6-A2Q7 and output transistor A2Q8. The voltage developed across A2R38 for the DVM output is referenced at the base of A2Q6 for comparison to the voltage at the RECORDER/LEVELER jack placed on the base of A2Q7. Any difference voltage creates an error voltage that changes the base-emitter bias on

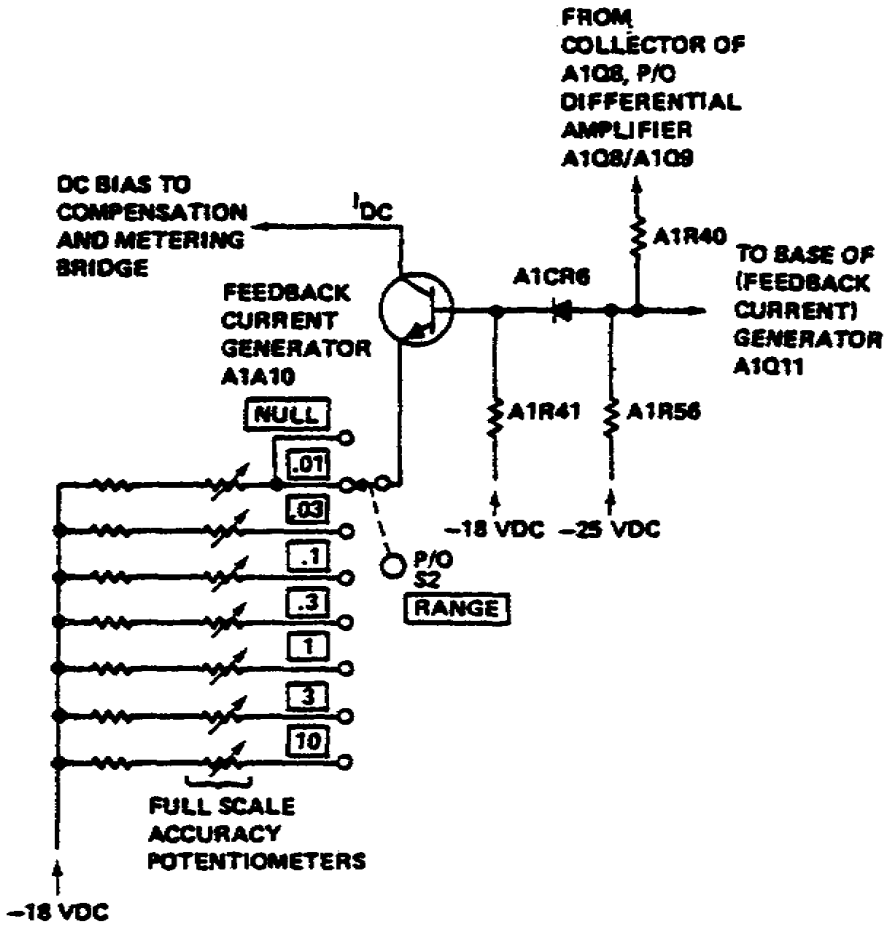


Figure 13. Feedback Current Generator.

A2Q8. A corresponding change in A2Q8 collector current occurs and the RECORDER/LEVELER voltage across A2R41 automatically adjusts to maintain the same magnitude as the DVM reference voltage.

(2) Squaring Circuit. A simplified schematic diagram of the squaring circuit is shown in Figure 14. The squaring circuit includes diodes A1CR9-14 and resistors A1R42-54. Temperature compensation for the squaring circuit is provided by A1CR15.

(3) The design of the squaring circuit is such that individual diodes are normally reverse-biased. The diodes are biased so that they conduct one after another at discrete values of emitter voltage. This causes the emitter resistance to be proportionately greater for larger currents. Thus, the collector current of A1Q11 is made to approximate a square law function, and the meter indicates power on a linear scale.

(4) Zeroing. The resistance of the Metering Bridge is never balanced. A small amount of unbalance must exist to provide error signal for the operation of the feedback loop. The Metering Bridge

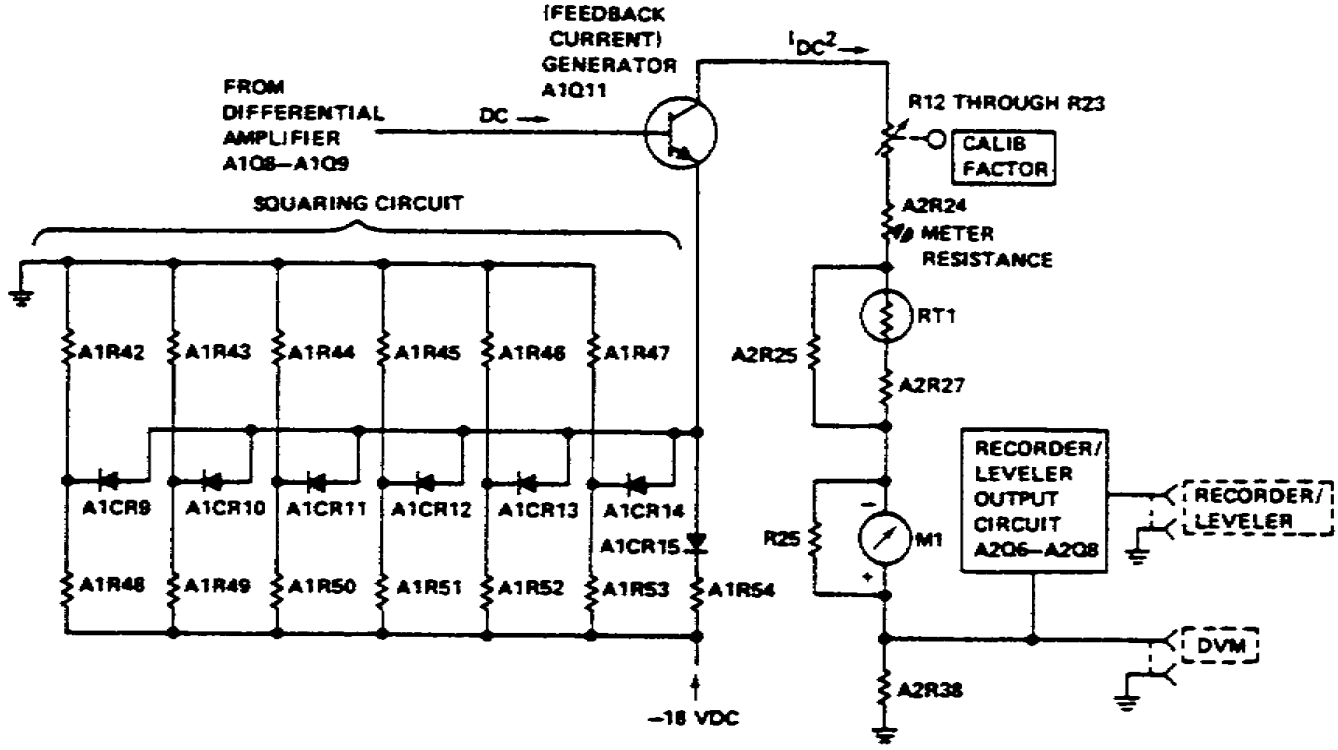


Figure 14. Meter Circuit.

loop circuit is self balancing and uses DC feedback to rebalance the closed loop. Resistive balance is set by R2A and R2B ZERO controls, front panel adjustments which are in one leg of the Metering Bridge. DC offset voltage on the base of A1Q8 determines the balance point of the closed loop. A1R37, ZERO CARRYOVER, sets the amount of this offset for about +50 millivolts.

p. DC Substitution.

A simplified schematic diagram of the DC Substitution and Calibration circuit is shown in Figure 15. An accurately determined DC current, I_{DC}, is supplied to the DC CALIBRATION terminals on the rear panel and adjusted to allow the RF detection bridge to precisely duplicate the RF power measurement reading. Calculation of DC power from the substituted DC current gives an accurate measure of the unknown RF microwave power.

q. Regulated Power Supply.

(1) A simplified schematic diagram of the power supply is shown in Figure 16. The power supply operates from either a 115 or

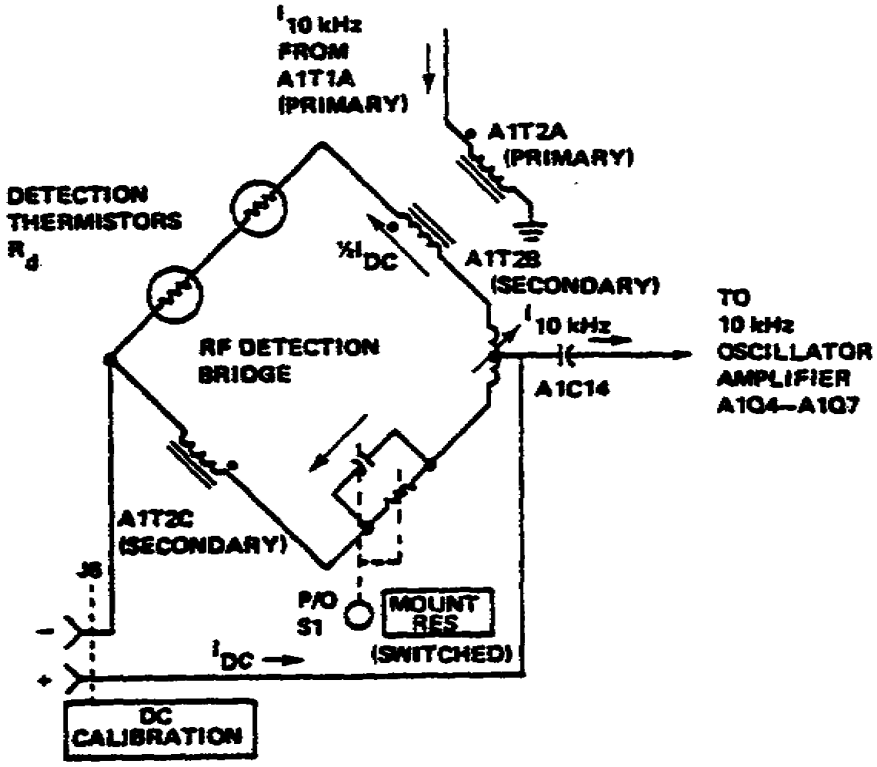


Figure 15. DC Calibration and Substitution.

230 volt, 50 to 400 Hz AC source or from an optional 24 volt, 30 mA rechargeable battery. Three voltages and two current outputs are provided by the power supply. Regulated voltages of -18, +1.3, and unregulated -25 VDC operate the power meter circuits. The current outputs are used for maintaining a trickle battery charge for recharging the battery.

(2) The -18 VDC is regulated by a conventional series regulator, A2Q1 through A2Q5. The unregulated -25 VDC is developed across A2CR1 and A2CR4. The +1.3 VDC is taken across the series diodes, A2CR6 and A2CR7. The -18 VDC Supply is adjusted by A2R36.

r. Power Switch.

A simplified schematic diagram of the power switch arrangement is shown in Figure 16. The POWER switch has five positions: LINE OFF, LINE ON, BATTERY ON, BATTERY TEST, and BATTERY CHARGE. In the line ON position the instrument operates from the conventional line voltage. If a rechargeable battery has been installed, a trickle charge is supplied to the battery. In the BATTERY ON position, instrument operation is dependent on the battery. In the BATTERY CHARGE position, -25 volts is connected to the battery for recharging. In the BATTERY TEST position, battery voltage can be measured on the 0-3 mW scale. Battery voltage

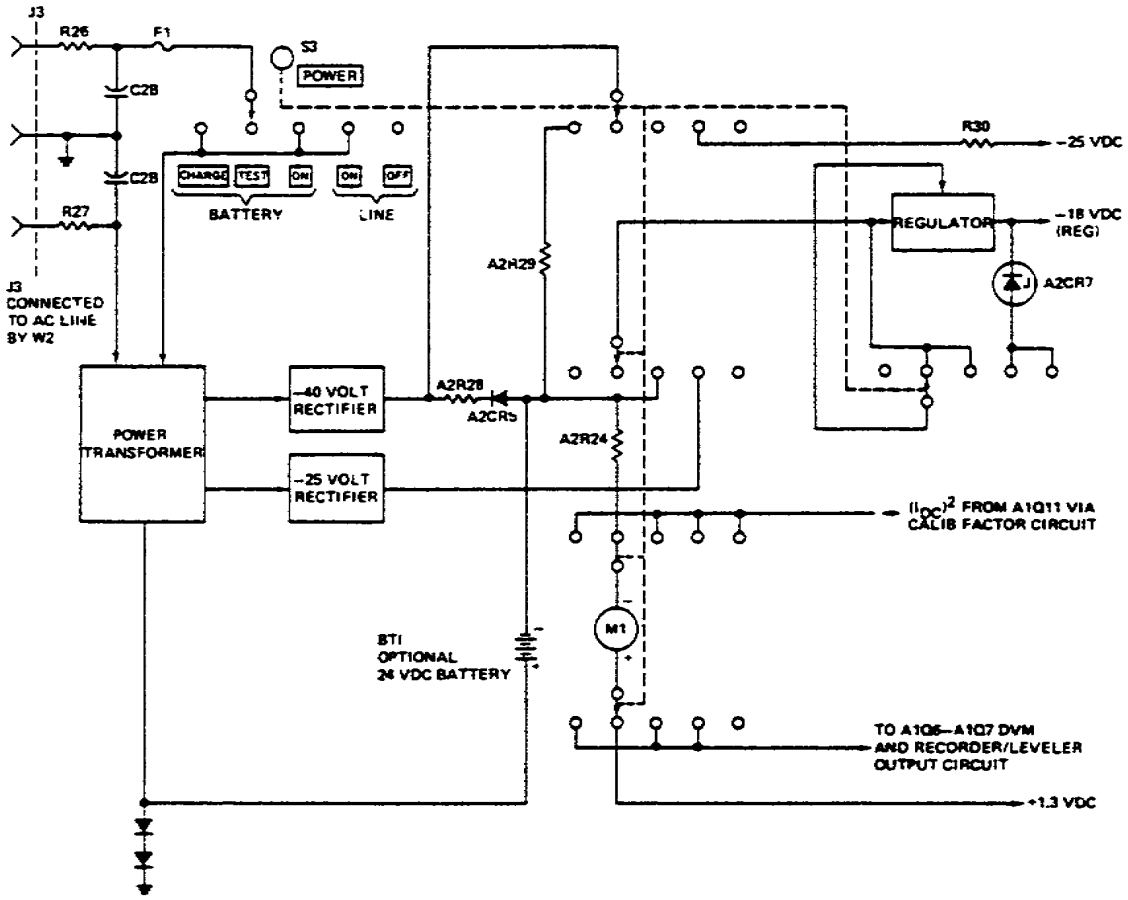


Figure 16. Power Switch Arrangement.

is 10 times meter scale reading. Proper charge of the battery is indicated by a reading within the BAT CHARGED region on the bottom of the meter face.

s. The Model 431C power meter is being replaced through attrition on the secondary transfer set by the Model 432A power meter.

3. MODEL 432A POWER METER.

a. Description (See Figure 17).

(1) The Model 432A Power Meter with temperature-compensated thermistor mounts, measures RF power from 10 microwatts (-20 dBM) to 10 milliwatts (+10 dBm) full scale with 1% of full scale accuracy from 10 MHz to 40 GHz. With a selector switch, the instrument normalizes the power meter reading to compensate for the Calibration Factor of a thermistor mount used for a given measurement. For portable operation, Option 01 instruments have a rechargeable nickel-cadmium battery. See Table 3 for complete specifications.

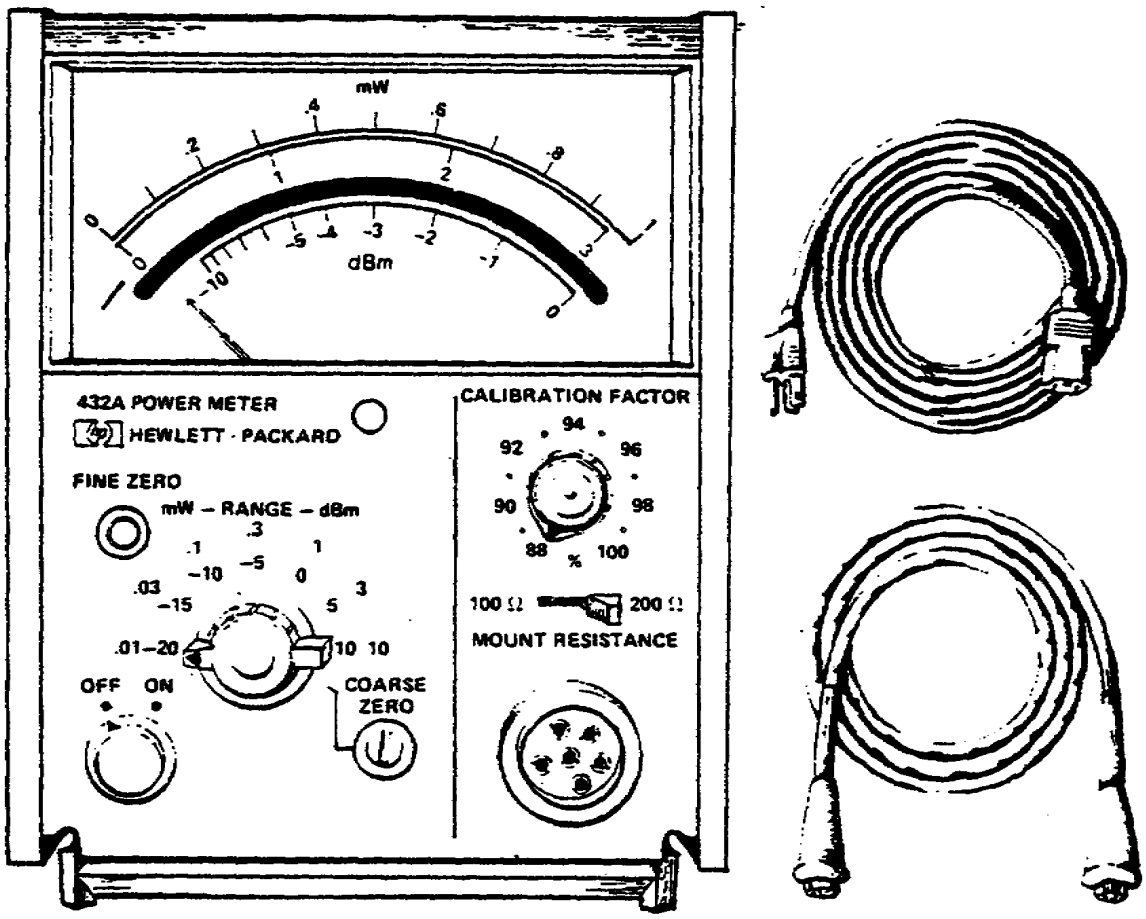


Figure 17. Model 432A Power Meter.

(2) The Model 432A has provision for DC substitution measurements and for power meter calibration. An output is provided for recorders or digital voltmeter readout.

(3) Accessories. Two accessories are supplied with the Model 432A Power Meter: a 7.5 foot (2290 mm) detachable power cable and a 5 foot (1520 mm) cable that connects the thermistor mount to the meter. Thermistor mounts are available but not supplied with the power meter (refer to Table 4). Table 1 lists those accessories supplied and also those available.

b. Primary Power Requirements.

The Model 432A operates from 115 or 230 volts AC line voltage. Line frequency may vary from 48 to 440 Hz. A slide switch on the rear panel is moved to the correct position for the line voltage available. Before operating the equipment, ensure that the fuse installed in the

Table 3. Specifications.

Instrument Type: Automatic, self-balancing power meter for use with temperature-compensated thermistor mount.

Power Range: 7 ranges with full-scale readings of 10, 30, 100, and 300 μW, 1, 3, and 10 mW, also calibrated in dBm from −20 dBm to +10 dBm full scale in 5-dB steps.

Accuracy: ±1% of full scale on all ranges (+0° C to +55° C).

Calibration Factor Control: 13-position switch normalizes meter reading to account for thermistor mount Calibration Factor.

Range: 100% to 88% in 1% steps.

Thermistor Mount: External temperature-compensated thermistor mounts required for operation (see Table 4).

Meter: Taut-band suspension, individually computer-calibrated, mirror-backed scales. Milliwatt scale more than 4-1/4 inches (108 mm) long.

Recorder Output: 1.000 volt into open circuit corresponds to full-scale meter deflection (1.0 on 0-1 scale) ±0.5%; 1000-ohm output impedance, BNC connector.

Note

Thermistor mount cable impedance is part of the 432A input bridge circuit. For cables 20 feet long and over, the bridge is matched to specific cable options, so the various cables should not be interchanged.

009: 10-foot (3, 05 m) cable for 100-ohm or 200-ohm mount.

010: 20-foot (6, 10 m) cable for 100-ohm or 200-ohm mount.

011: 50-foot (15, 24 m) cable for 100-ohm or 200-ohm mount.

012: 100-foot (30, 48 m) cable for 100-ohm or 200-ohm mount.

013: 200-foot (60, 96 m) cable for 100-ohm or 200-ohm mount.

Table 4. Thermistor Mounts for the 432A.

Model	Frequency Range (GHz)	Operating Resistance (Ohms)
COAXIAL MOUNTS:		
478A (Type N Connector)	0.01–10	200
8478B (Type N Connector)	0.01–18	200
8478B–Option 11 (APC-7 Connector)	0.01–18	200
WAVEGUIDE MOUNTS:		
S486A	2.6–3.95	100
G486A	3.95–5.85	100
J486A	5.3–8.2	100
H486A	7.05–10	100
X486A	8.2–12.4	100
M486A	10–15	100
P486A	12.4–18	100
K486A	18–26.5	200
R486A	26.5–40	200

instrument corresponds to the value marked on the panel for the line voltage available (1/8 amp slo-blow).

c. Introduction.

(1) The Model 432A Power Meter operates with temperature-compensated thermistor mounts such as the 8478B and 478A Coaxial, and 486A Waveguide series. The frequency range of the 432A with these mounts in 50 ohm coaxial systems is 10 mHz to 18 GHz; in waveguide systems it is 2.6 GHz to 40 GHz. Full-scale power ranges are 10 microwatts to 10 milliwatts (-20 dBm to +10 dBm). Extended measurements may be made to 1 microwatt (-30 dBm). The total measurement capacity of the instrument is divided into seven ranges, selected by a front-panel RANGE switch.

(2) This section describes general operating procedures and error analysis in microwave power measurement.

d. Controls, Connectors, and Indicators.

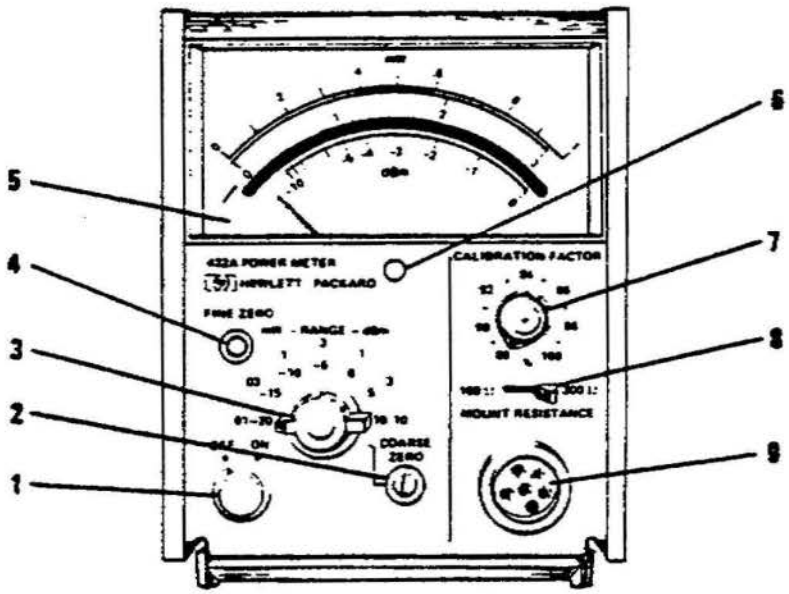
(1) The front and rear panel controls, connectors, and indicators are explained in Figures 18 and 19. The descriptions are keyed to the corresponding items which are indicated on each figure.

(2) The COARSE ZERO and FINE ZERO controls zero the meter. Zero carryover from the most sensitive range to the six ranges is within ±0.5%. When the RANGE switch is set to COARSE ZERO, the meter indicates thermistor bridge unbalance, and the front panel COARSE ZERO adjust is for initial bridge balance. For best results, FINE ZERO the 432A on the particular meter range in use. For turn on and zeroing procedure refer to Figure 20.

(3) The CALIBRATION FACTOR switch provides discrete amounts of compensation for measurement uncertainties related to SWR and thermistor mount efficiency. The Calibration Factor value permits direct meter reading of the RF Power delivered to an impedance equal to the characteristic impedance (Z_O) of the transmission line between the thermistor mount and the RF source. Calibration Factor values are marked on the label of each 8478B, 478A or 486A Thermistor Mount.

(4) The MOUNT RESISTANCE switch on the front panel compensates for three types of thermistor mounts. Model 486A waveguide mounts can be used by setting the MOUNT RESISTANCE switch to 100 ohm or 200 ohm, depending on the thermistor mount used (refer to Table 4). The 200 ohm position is used with Models 478A and 8478B Thermistor Mounts.

(5) The rear-panel BNC connector labeled RECORDER provides an output voltage linearly proportional to the meter current; 1 volt into an open circuit equals full-scale meter deflection. This voltage is developed across a 1 K resistor; therefore, when a recorder with a 1 K input impedance is connected to the RECORDER output, approximately



1. POWER. Instrument power ON/OFF switch; connects either AC line voltage or internal battery to internal battery to internal voltage regulator circuits. When AC power is on, optional battery charging circuit operates.

2. COARSE ZERO. Meter zero adjustment; set the RANGE selector to COARSE ZERO, turn OFF the RF power, and adjust to zero the meter.

3. RANGE. Power measurement range selector; selects ranges from 0.01 to 10 milliwatts (-20 to +10 dBm). COARSE ZERO setting is used to zero meter with no power applied to thermistor mount.

4. FINE ZERO. Electronic zero that balances the compensation bridge with zero RF input. To zero meter during operation, close the switch momentarily. Be sure that RF power is not applied to the thermistor mount when the FINE ZERO switch is depressed.

5. Meter. Indicates power input to thermistor mount in milliwatts and dBm. To use the dBm scale, note the value in dBm of the range in use, and subtract from it the reading on the meter dBm scale.

6. Mechanical Meter Zero. Sets meter suspension so that meter indicates zero. To adjust the zero:

   a. Turn POWER switch off.

   b. Turn the adjustment screw clockwise until the indicator falls below zero and comes back up to zero again.

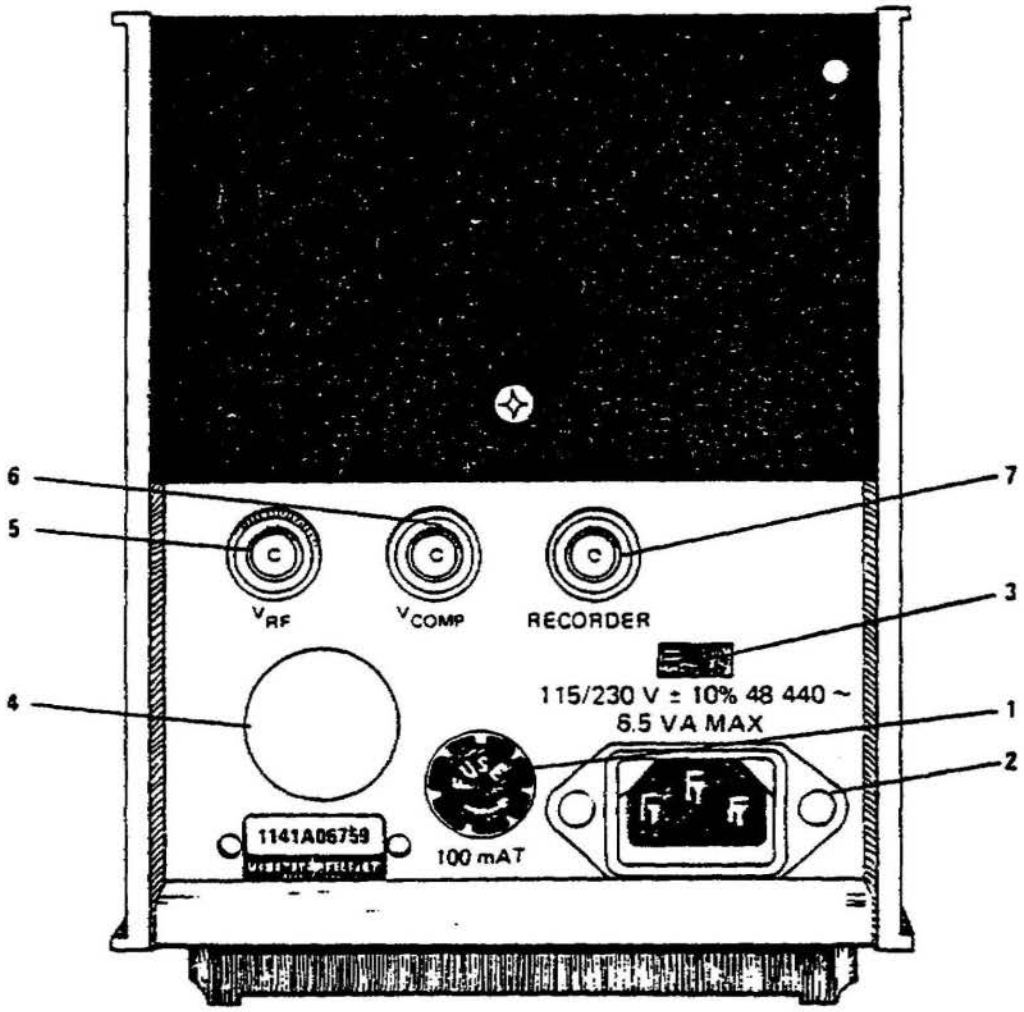
   c. Turn the adjustment very slightly counterclockwise to free up the mechanism from the adjusting peg.

7. CALIBRATION FACTOR. Amplifier gain compensation selector. Set to correspond to the calibration factor printed on the thermistor mount body.

8. MOUNT RESISTANCE. Selects resistance equal to that of mount in use to balance bridges. Table 4 lists the thermistor mounts and resistances. Set with meter power OFF, when mount is initially connected to the meter.

9. Thermistor Mount Cable Connector. Input connector for 5-1/2 foot cable that connects to the 478A, 8478B, or 486A Thermistor Mounts.

Figure 18. Front Panel Controls, Connectors and Indicators.



1. Line Fuse. For 115 Vac or for 230 Vac use 1 A amp fuse.

2. Power Cord Input. Use power cord provided, 8120-0078. Line power limits are 115 230 Vac, 48-440 Hz. Check FUSE rating and position of line voltage slide switch before connecting power.

3. Line Voltage Slide Switch. Set to line voltage available (115 or 230 Vac, 48-440 Hz).

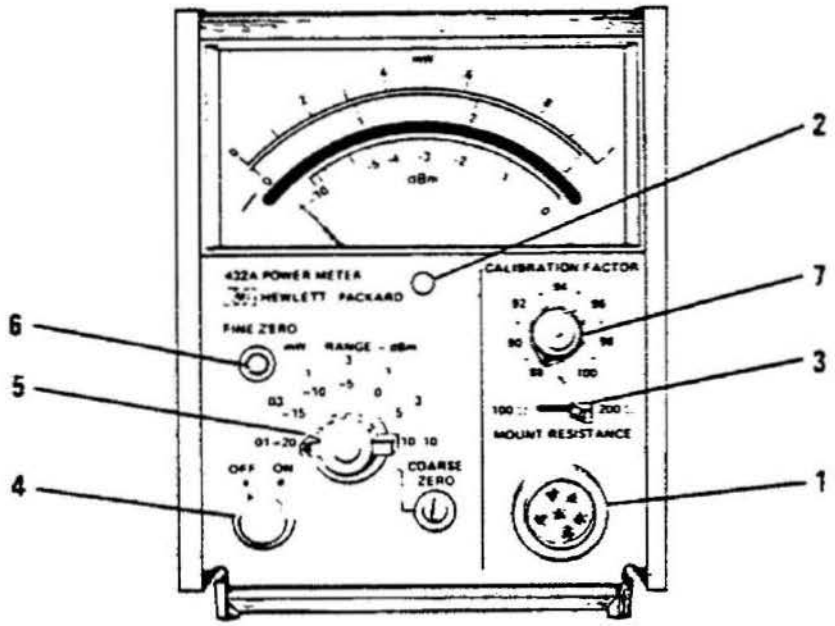
4. Mounting Hole for Option 002 Model Power Meters. Thermistor mount cable connector installed and wired in parallel with front-panel connector. Only one mount at a time may be used with the power meter.

5. V_{RF} Input. Connected directly to RF bridge. Used for calibrating power Meter with 8477A Power Meter Calibrator. Also used for precision power measurements.

6. V_{COMP} Input. Connected directly to compensation bridge. Used for calibrating power meter with 8477A Power Meter Calibrator. Also used for precision power measurements.

7. RECORDER OUTPUT. Voltage from meter circuit to be used for recorder or digital voltmeter. Output impedance is approx. 1000Ω.

Figure 19. Rear Panel Controls and Connectors.



1 Connect the thermistor mount and cable to THERMISTOR MOUNT connector. Refer to Table 2 for recommended thermistor mounts and their frequency ranges.

2 Meter Mechanical Zero.

a. With the instrument turned off, rotate the meter adjustment screw clockwise until the pointer approaches the zero mark from the left.

b. Continue the clockwise rotation until the pointer coincides with the zero mark. If the pointer overshoots, continue rotating the adjustment screw clockwise until the pointer once again approaches the zero mark from the left.

c. Rotate the adjustment screw about three degrees counterclockwise to disengage screw adjustment from the meter suspension.

3. Set the MOUNT RES switch to correspond to the operating resistance of thermistor mount used.

4 Turn the 432A POWER switch ON. For battery operation, the AC LINE indicator does not turn on.

5 Set the RANGE selector to COARSE ZERO and then zero the meter with the COARSE ZERO screwdriver adjustment.

Note

The power meter should be zeroed with the RF power source turned off, or the mount disconnected from the source.

6 Set the range selector to the 0.01 mW range, then depress the FINE ZERO switch until the meter indicates zero.

Note

Range-to-range zero carryover is less than ±0.5% if the meter zero has been adjusted (step 2 above), and the instrument has been properly zero-set on the sensitive range. For maximum accuracy, zero-set the power meter on the range to be used.

7 Set CALIB FACTOR switch to correspond to Calibration Factor imprinted on thermistor mount label.

8. Apply RF power to the thermistor mount. Power is indicated on the meter directly in mW or dBm.

Figure 20. Turn On and Zeroing Procedure.

0.5 volt will equal full scale deflection. This loading of the RECORDER output has no effect on the accuracy of the 432A panel meter.

(6) A digital voltmeter can be connected to the rear panel RECORDER output for more resolution of power meter readings. When a voltmeter with input impedance greater than 1 megohm is connected to the RECORDER output, 1 volt equals full scale deflection.

(7) The 432A has two calibration jacks (V_{RF} and V_{COMP}) on the rear panel that can be used for precision power measurements. Instrument error can be reduced from ±1% (0.2% of reading + 5 μW) of reading, depending on the care taken in measurement and on the accuracy of auxiliary equipment.

e. Microwave Power Measurement Accuracy.

(1) A number of factors affect the overall accuracy of power measurement. The major sources of error are mismatch error, RF losses, and instrumentation error.

(2) Mismatch Error. In a practical measurement situation, both the source and thermistor mount have SWR, and the source is seldom matched to the thermistor mount unless a tuner is used. The amount of mismatch loss in any measurement depends on the total SWR present. The impedance that the source sees is determined by the actual thermistor mount impedance, the electrical length of the line, and the characteristic impedance of the line, Z_O.

(3) In general, neither the source nor the thermistor mount has Z_O impedance, and the actual impedances are known only as reflection coefficients, mismatch losses, or SWR. The power delivered to the thermistor mount, and hence the mismatch loss, can only be described as being somewhere between two limits. The uncertainty of power measurement due so mismatch loss increases with SWR. Limits of mismatch loss are generally determined by means of a chart such as the Mismatch Loss Limits charts in Figures 6 and 7. The total mismatch loss uncertainty in power measurement is determined by algebraically adding the thermistor mount losses to the uncertainty caused by source and thermistor mount Z_O match.

(4) RF Losses. RF losses account for the power entering the thermistor mount but not dissipated in the detection thermistor element. Such losses may be in the walls of a waveguide mount, the center conductor of a coaxial mount, capacitor dielectric, poor connections within the mount, or due to radiation.

(5) Instrumentation Error. The degree of inability of the instrument to measure the substitution power supplied to the thermistor mount is called power meter accuracy or instrumentation error. Instrumentation error of the Model 432A is ±1% of full scale, 0°C to +55°C.

f. Calibration Factor and Effective Efficiency.

(1) Calibration factor and effective efficiency are correction factors for improving power measurement accuracy. Both factors are marked on every thermistor mount. Calibration factor compensates for thermistor mount VSWR and RF losses whenever the thermistor mount is connected to an RF source without a tuner. Effective efficiency compensates for thermistor mount RF losses when a tuner is used in the measurement system.

(2) When the 432A CALIBRATION FACTOR selector is set to the appropriate factor indicated on the thermistor mount, the power indicated by the meter is the power that would be delivered by the source to a load impedance equal to Z_o. More accurately, the relationship between indicated power and the power available to a Z_o load is given by the following equation:

$$P_o = \frac{P \text{ indicated } (1 \pm p_s p_m)^2}{\text{Calibration Factor}}$$

where

P_o = power available to a Z_o load

p_s = source reflection coefficient

p_m = thermistor mount reflection coefficient

$$p = \frac{SWR - 1}{SWR + 1}$$

Calibration factor does not compensate for source VSWR, or for multiple reflections between the source and the thermistor mount.

(3) To minimize mismatch between the source and the thermistor mount without a tuner, insert a low SWR precision attenuator in the transmission line between the thermistor mount and the source. Since the mount impedance (and corresponding SWR) deviates significantly only at the high and low ends of a microwave band, it is generally unnecessary to use a tuner. A tuner or other effective means of reducing mismatch or when more accuracy is required.

g. Precision Power Measurement.

(1) General. Using precision instruments and careful procedures, measurement error can be reduced to 0.2% of reading to +0.5 μW. The technique involves: 1) zeroing the bridge circuits and measuring the bridge amplifier output voltage difference with a digital voltmeter, then 2) connecting RF power to the thermistor mount and then measuring the bridge amplifier output voltage difference again, and 3) calculating

the power from the two measurements. Figure 21 shows the instrument setup for DC substitution measurement. A digital voltmeter with at least a ±0.05% DC accuracy.

(2) Measurement Procedure.

(a) Connect the DVM to the 432A rear panel V_{COMP} and V_{RF} outputs. Be sure that the digital voltmeter input is isolated from chassis ground.

(b) Turn off, or disconnect the RF power from the thermistor mount.

(c) Zero the 432A with the COARSE ZERO controls.

(d) Depress the FINE ZERO toggle, and measure the differential voltage (V_0) between V_{COMP} and V_{RF}

(e) Release the FINE ZERO toggle, and turn on, or reconnect the RF power to the thermistor mount.

(f) Measure again the differential voltage (V_1) between V_{RF} and V_{COMP}.

$$V_1 = V_{COMP} - V_{RF}$$

(g) Measure V_{COMP} to ground.

h. Simplified Description.

(1) The 432A Power Meter consists of two major sections: the bridge and meter logic assemblies. The instrument also contains an auto zero circuit which provides for automatic zeroing on any range. A simplified block diagram of the 432A is shown in Figure 22.

(2) The bridge section contains circuits which form two self-balancing bridge circuits when a suitable thermistor mount is connected to the 432A. Each bridge is automatically brought to balance by the action of a high gain DC amplifier feeding power to the top of the bridge. The voltage at the top of the RF bridge, V_{RF}, is responsive to both input RF power and ambient temperature changes. The voltage at the top of the compensation bridge, V_{COMP} is responsive only to ambient temperature changes. Knowing V_{RF} and V_{COMP}, the RF power can be calculated.

(3) The meter logic section processes V_{RF} and V_{COMP} to produce a meter current proportional to RF power. The sum (V_{RF} + V_{COMP}) controls the width of 5 kHz pulses. The difference (V_{COMP} - V_{RF}) is chopped,

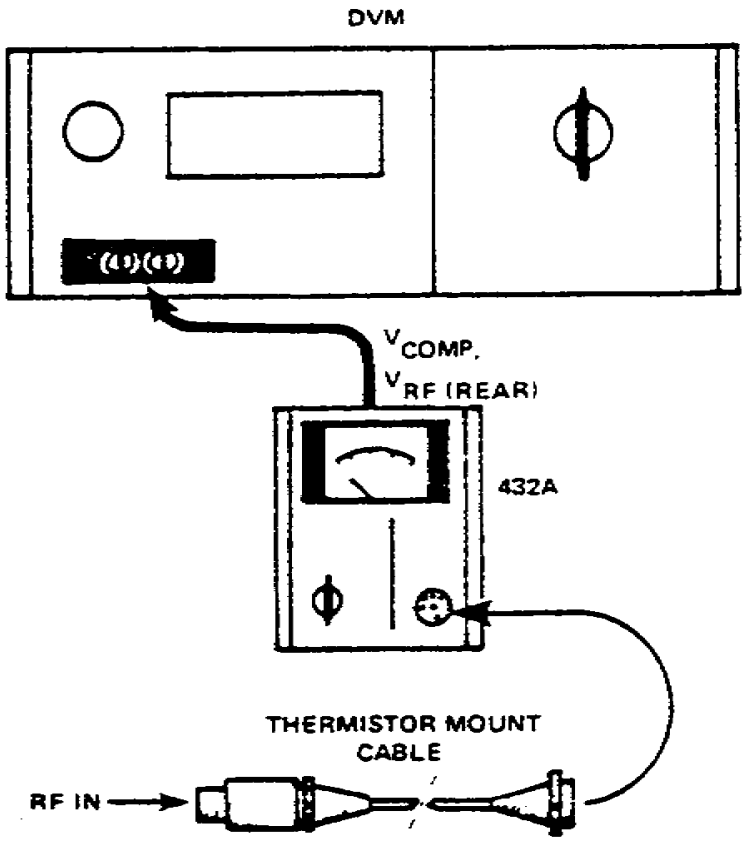


Figure 21. Precision Power Measurements.

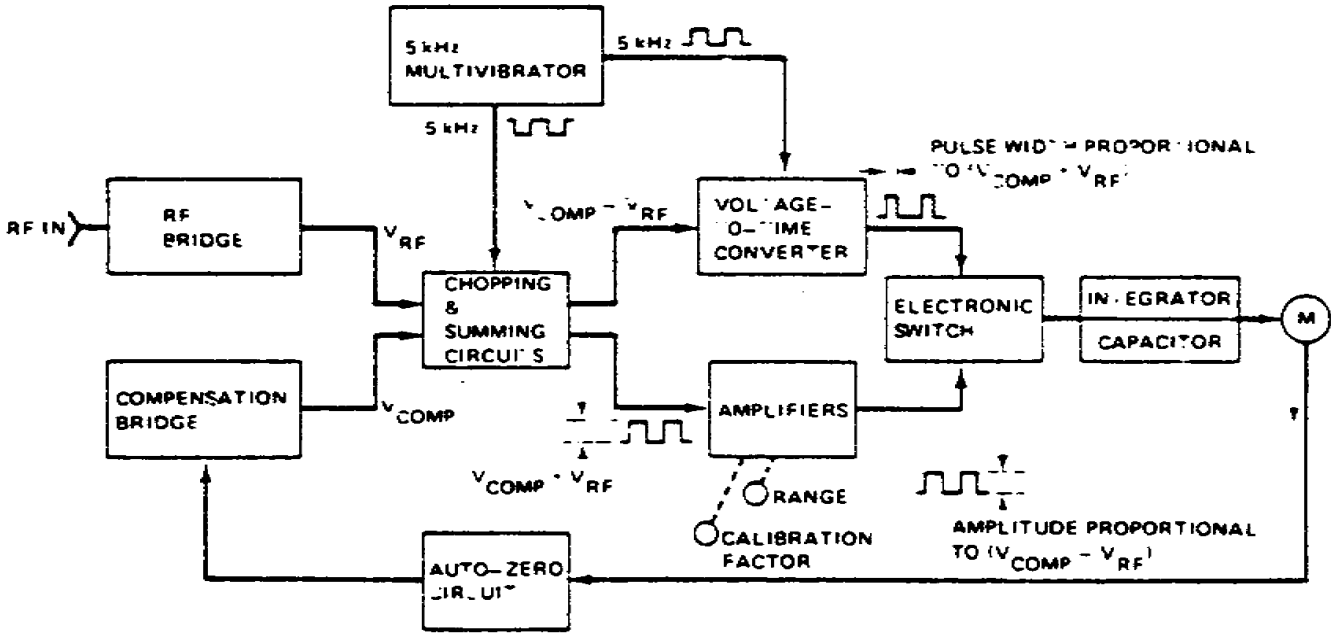


Figure 22. Simplified 432A Block Diagram.

amplified and fed to an electronic switch actuated by the controlled width pulses. Therefore, the meter current is pulses of variable height and width with the meter indicating the average current. (This process produces a meter current proportional to $(V_{RF} + V_{COMP})$ $(V_{RF} - V_{COMP})$. Paragraph 2i(6) explains why this is necessary.

i. Functional Block Diagram.

(1) A functional block diagram of the 432A power meter is shown in Figure 23. The instrument comprises two major assemblies: bridge assembly A1 and meter logic assembly A2. Auto zero circuit A1A1, which provides for automatic zeroing of the instrument, is included as part of logic assembly A1.

(2) The thermistor bridges are biased with direct current from the bridge amplifiers. Each bridge amplifier supplies enough heating current to bring the thermistor resistance to 100 or 200 ohms, depending upon the setting of the MOUNT RESISTANCE switch on the 432A. If one of the thermistor bridges is unbalanced due to incorrect thermistor resistance, an error voltage occurs and is amplified by the bridge amplifier. The error voltage is applied to the top of the bridge and changes the power dissipation of the negative temperature coefficient thermistor. The change of power dissipation causes the resistance to the thermistor to change in the direction required to balance the bridge. Application of RF power to the RF bridge heats the thermistor and lowers its resistance. The bridge circuit responds by reducing the DC voltage applied to the top of the bridge thus maintaining bridge balance.

(3) If ambient temperature causes changes in the thermistor resistance, the bridge circuits respond by applying an error voltage to the bridges to maintain bridge balance. The voltage at the top of the RF bridge is dependent upon both ambient temperature and the RF input. The voltage at the top of the compensation bridge is dependent upon the ambient temperature only. The power meter reading is brought to zero with no applied RF power by making V_{COMP} equal to V_{RF} so $(V_{COMP} - V_{RF})$ equal zero. Since ambient temperature causes both thermistors to respond similarly, there will be no net difference between the amplifier output voltages. Therefore, any difference in output voltages from the bridges is now due to RF power absorbed by the thermistor mount.

(4) The RF bridge voltage, V_{RF}, and the compensation bridge voltage, V_{COMP}, contain the "RF power" information. To provide a meter reading proportional to RF power, the DC voltages (V_{RF}, V_{COMP}) must be further processed by the meter logic circuits.

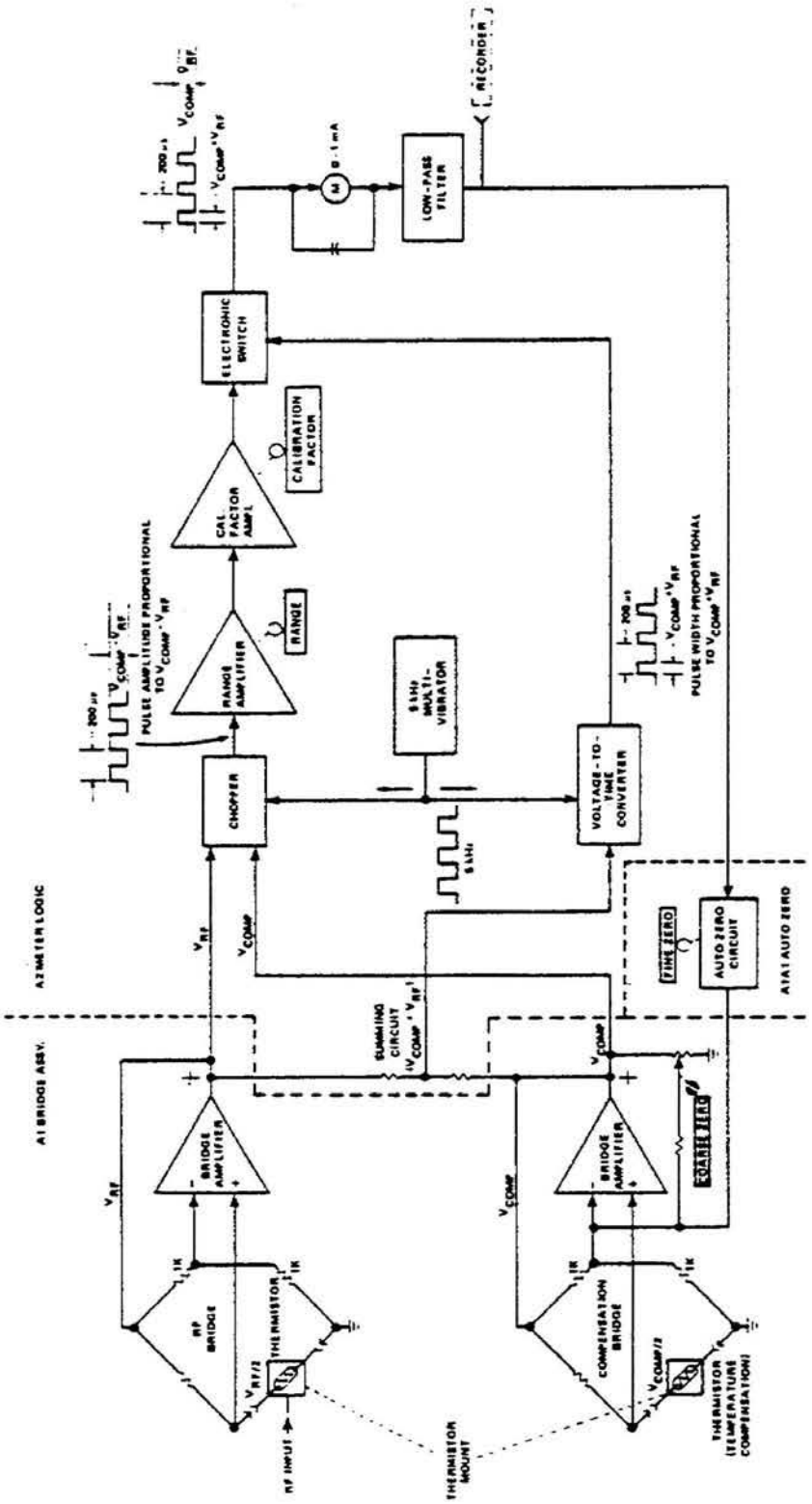


Figure 23. Model 432A Block Diagram.

(5) The required processing is derived as follows: P_0 is absorbed power needed by the RF thermistor to bring its resistance to R ohms (100 or 200 ohms). P_0 consists of two components: RF power and DC power supplied by the 432A. The self-balancing action of the bridge circuit automatically adjusts the DC power so that the total power in the thermistor is P_0. This DC power is related to the voltage V_{RF} at the top of the bridge by $(V_{RF}/2)^2/R$. Thus

$$P_0 = \text{RF power} + \text{DC power}$$

$$= \text{RF power} + \frac{V_{RF}^2}{4R}$$

(6) RF power can be determined by measuring V_{RF} with and without applied RF power and then doing some arithmetic. But this power measuring scheme is neither convenient nor temperature compensated (since P_0 changes with temperature). The 432A introduces another thermistor bridge circuit exposed to the same ambient temperature but not RF power. This circuit includes adjustments (COARSE and FINE ZERO) so that the DC voltage V_{COMP} at the top of its bridge can be set equal to V_{RF}. Assuming matched RF and compensation thermistors, V_{RFO} (with no RF power) and V_{COMP} remain equal with ambient temperature fluctuation. They differ only when the RF power to be measured is applied to the RF thermistor. Thus, we have

$$V_{COMP} = V_{RFO}$$

when RF power = 0 and

$$P_0 = 0 + \frac{V_{COMP}^2}{4R}.$$

Combining equations, we have:

$$\frac{V_{COMP}^2}{4R} = \text{RF power} + \frac{V_{RF}^2}{4R}$$

or

$$\text{RF power} = \frac{V_{COMP}^2 - V_{RF}^2}{4R} = \frac{1}{4R}\,(V_{COMP} + V_{RF})\,(V_{COMP} - V_{RF})\ .$$

(7) Thus an RF power measurement reduces to setting $V_{COMP} = V_{RFO}$ (with zero RF power) initially, measuring V_{COMP} and V_{RF}, and computing with the above formula. The 432A carries out the computation by forming the indicated sum and difference, performing the multiplication and displaying the result on a meter.

(8) The meter logic circuits change the two DC voltages to two pulse signals which contain all the RF power information. One of the signals will be a square wave whose amplitude is proportional to $V_{COMP} - V_{RF}$. The other signal will have a pulse width proportional to $V_{COMP} + V_{RF}$.

(9) The $V_{COMP} - V_{RF}$ signal is obtained by taking the DC voltage outputs from the A1 assembly and applying them to a chopper circuit. This chopper circuit is driven by a 5 KHz multivibrator. The output of the chopper is a square wave signal whose amplitude is proportional to $V_{COMP} - V_{RF}$. The output of the chopper is coupled to the range amplifier and then to the calibration factor amplifier. The amplification that the signal receives in these two amplifiers depends upon the setting of the RANGE switch and the CALIBRATION FACTOR switch. The output of the calibration factor amplifier is V. This current is fed to the electronic switch. A square wave current with amplitude proportional to $(V_{COMP} - V_{RF})$.

(10) The $V_{COMP} + V_{RF}$ signal is obtained by taking the two DC voltages from A1 assembly through a summing circuit and feeding this voltage to a voltage-to-time converter. The voltage-to-time converter is driven by a 5 kHz multivibrator. The output of the voltage-to-time converter is a signal whose pulse width is proportional to he sum of $V_{COMP} + V_{RF}$. The signal controls the electronic switch. From the $V_{COMP} - V_{RF}$ and $V_{COMP} + V_{RF}$ inputs, the electronic switch provides a 5 kHz pulse train whose amplitude is proportional to $V_{COMP} - V_{RF}$ and whose pulse width is proportional to $V_{COMP} + V_{RF}$. The pulse width is always 90 msec or less.

(11) The bias circuit switch and filter provide a zero current reference for the meter circuits. This is accomplished by controlling the DC bias to the first stage of the calibration factor amplifier. This circuit, in effect, restores the DC component to the square wave which has been amplified by AC coupled amplifiers.

(12) The meter is a 0-1 mA, full-scale meter chat has a capacitor across its terminals. The capacitor integrates the output pulses from the current switch so the current into the meter is proportional to the time average of the input pulses. That is, the input current to the meter is proportional to the product of

$$(V_{COMP} + V_{RF})\ (V_{COMP} - V_{RF})$$

$$= (V_{COMP})^2 - (V_{RF})^2$$

(13) The output from the meter is further filtered so the voltage at the rear panel RECORDER output is suitable for use with either a digital voltmeter or X-Y recorder. The RECORDER output voltage is returned to the compensation bridge through the automatic zero circuit when the FINE ZERO switch is depressed. The automatic zero circuit holds a correction voltage at the input of the compensation bridge amplifier, so when the RF is zero, the meter indication will also be zero.

(14) The functional block diagram is further broken down in Figures 24, 25, and 26 with sheets 1 of 2 being the schematic and 2 of 2 a talking schematic used for explanation of the circuitry.

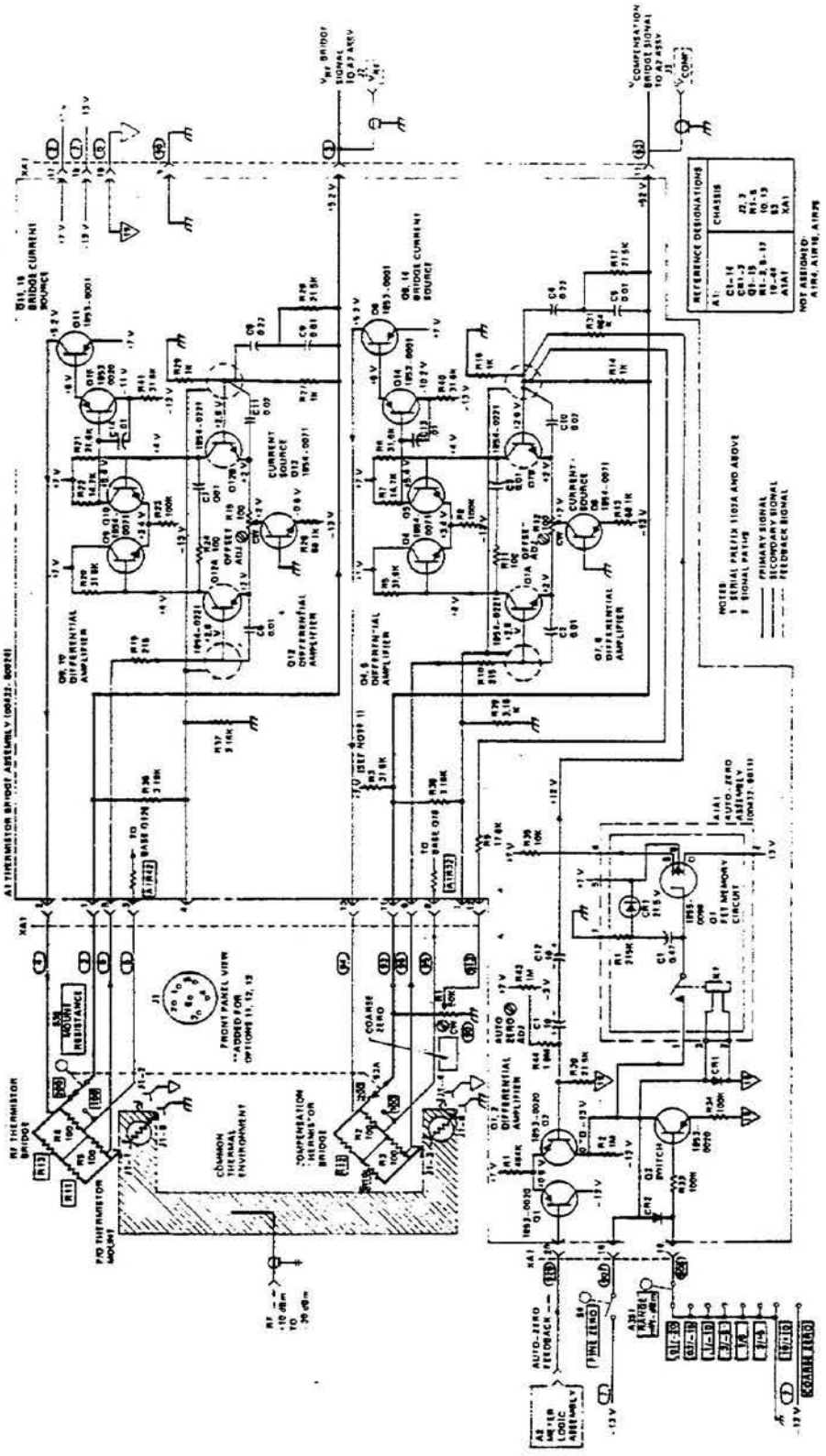


Figure 24A. Model 432A RF bridge talking schematic.

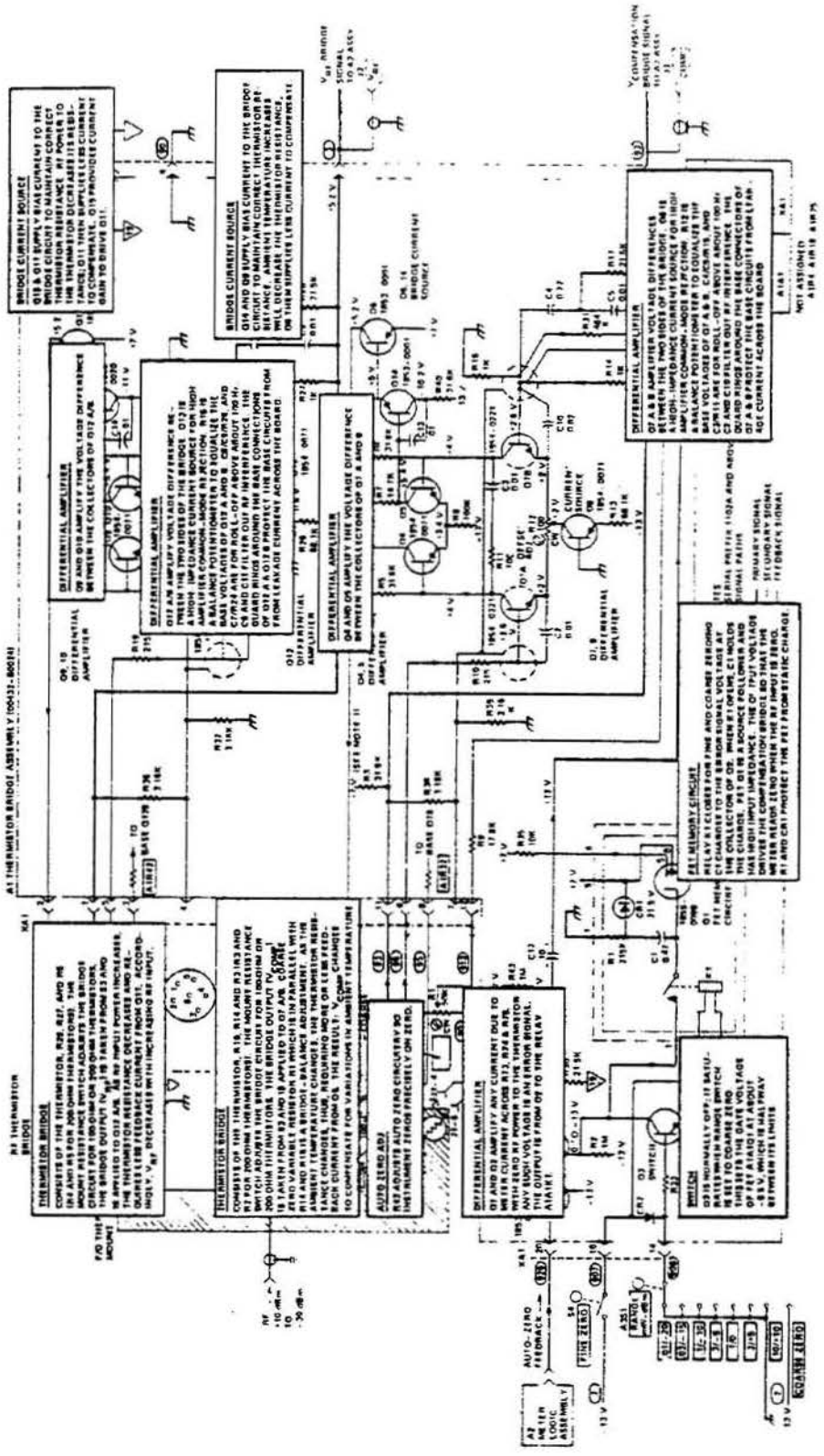


Figure 24B. Model 432A bridge talking schematic

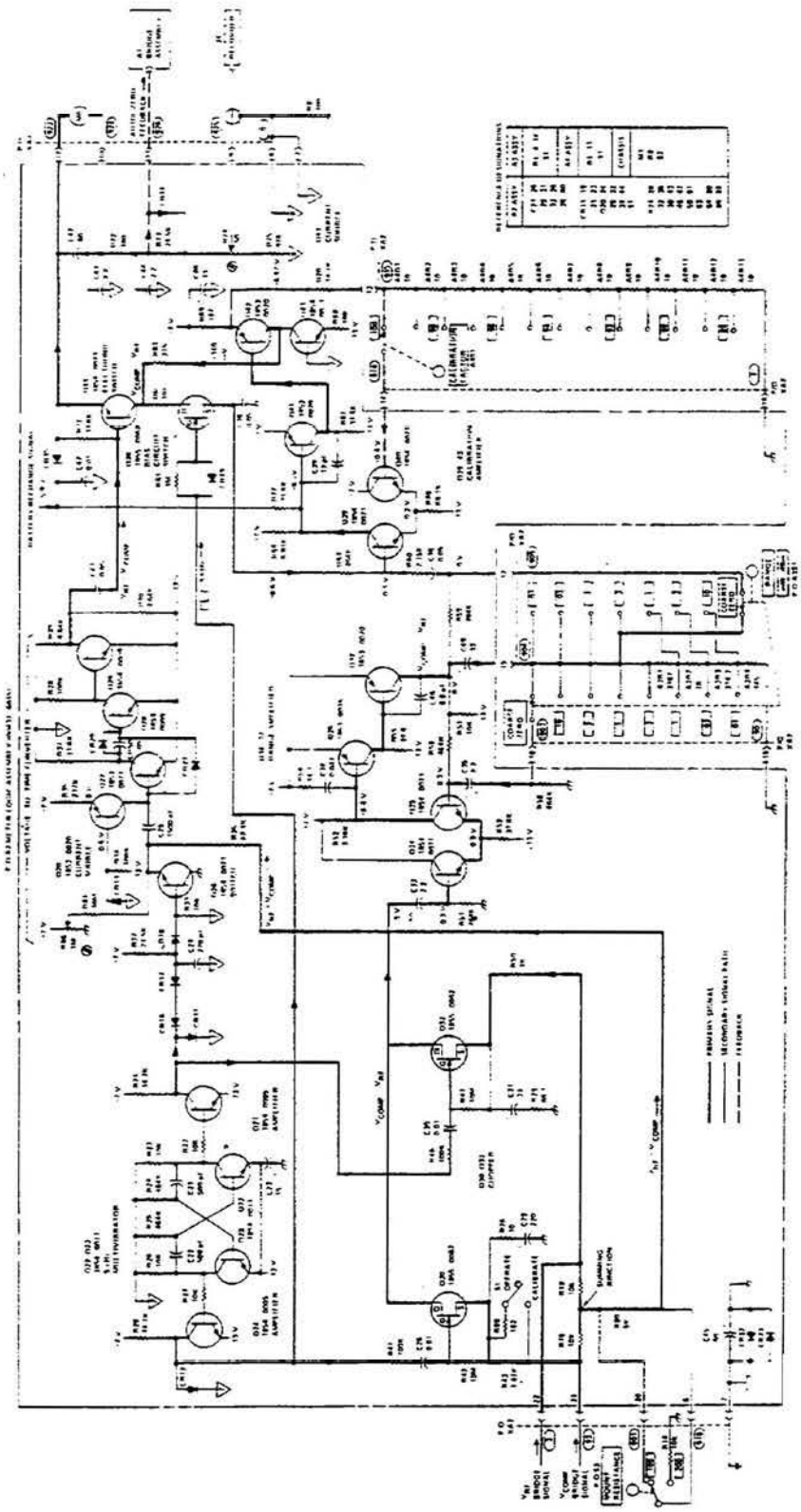


Figure 25A. Model 432A meter logic talking schematic.

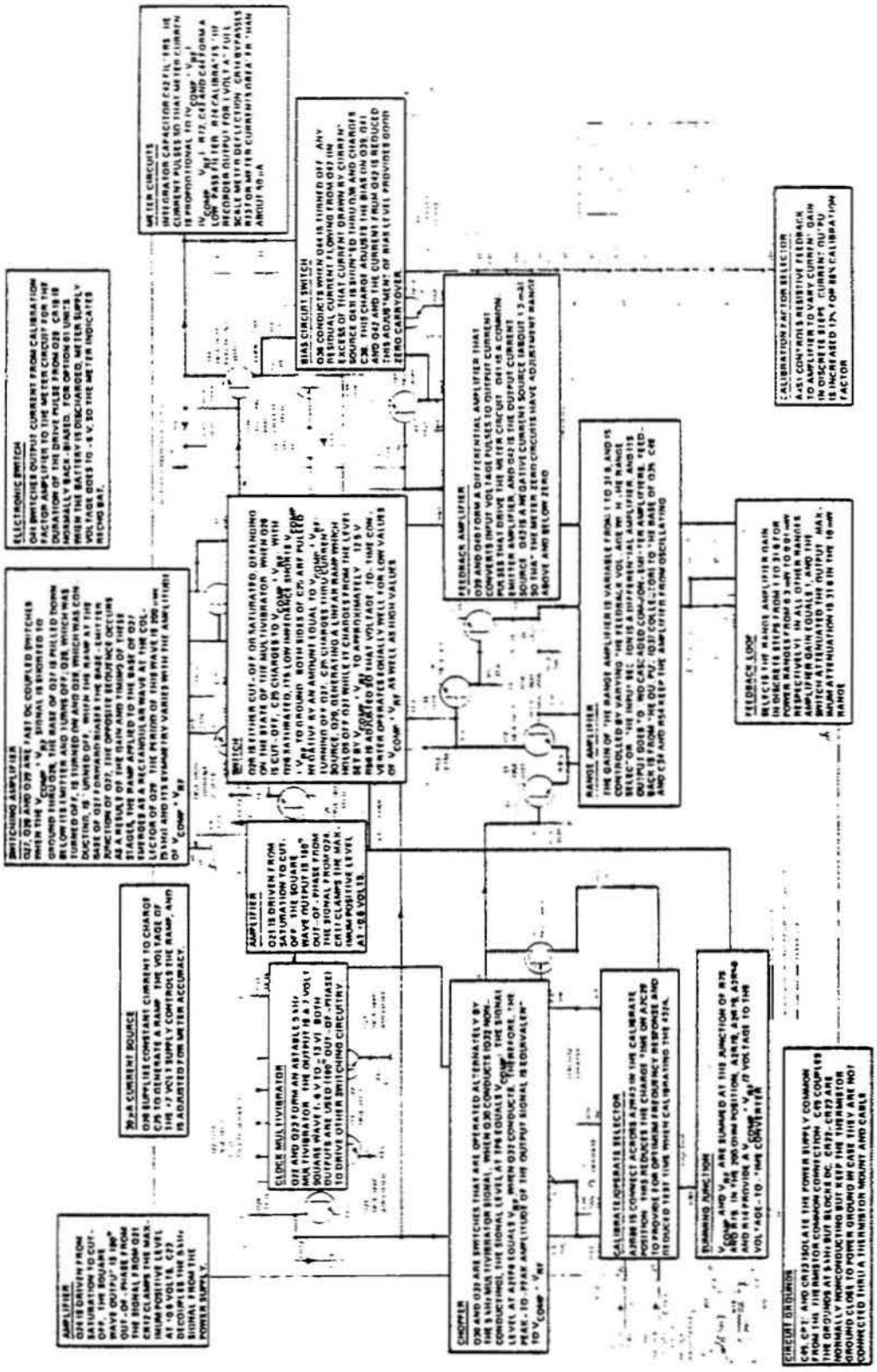


Figure 25B. Model 432A meter logic talking schematic.

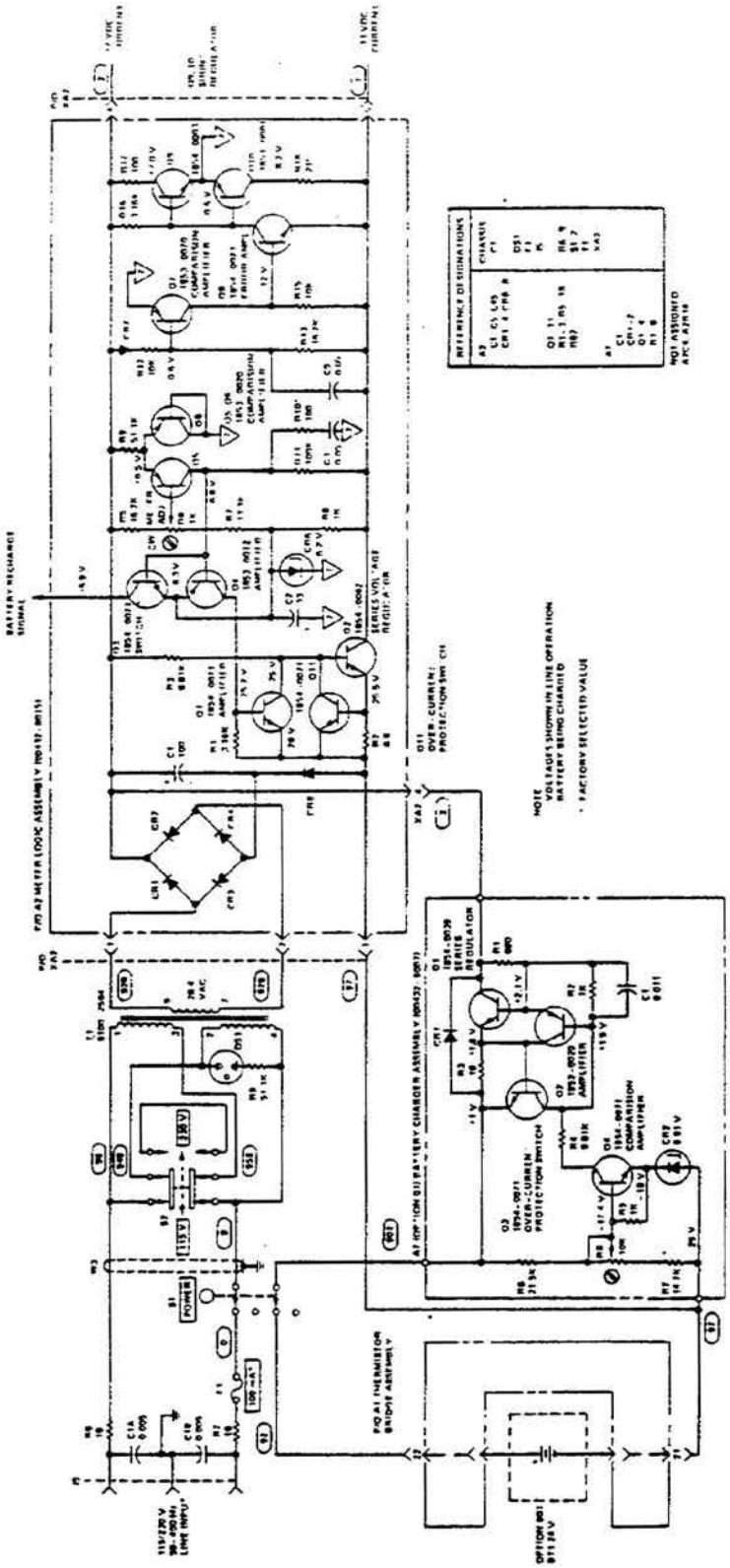


Figure 26A. Model 432A power supply talking schematic.

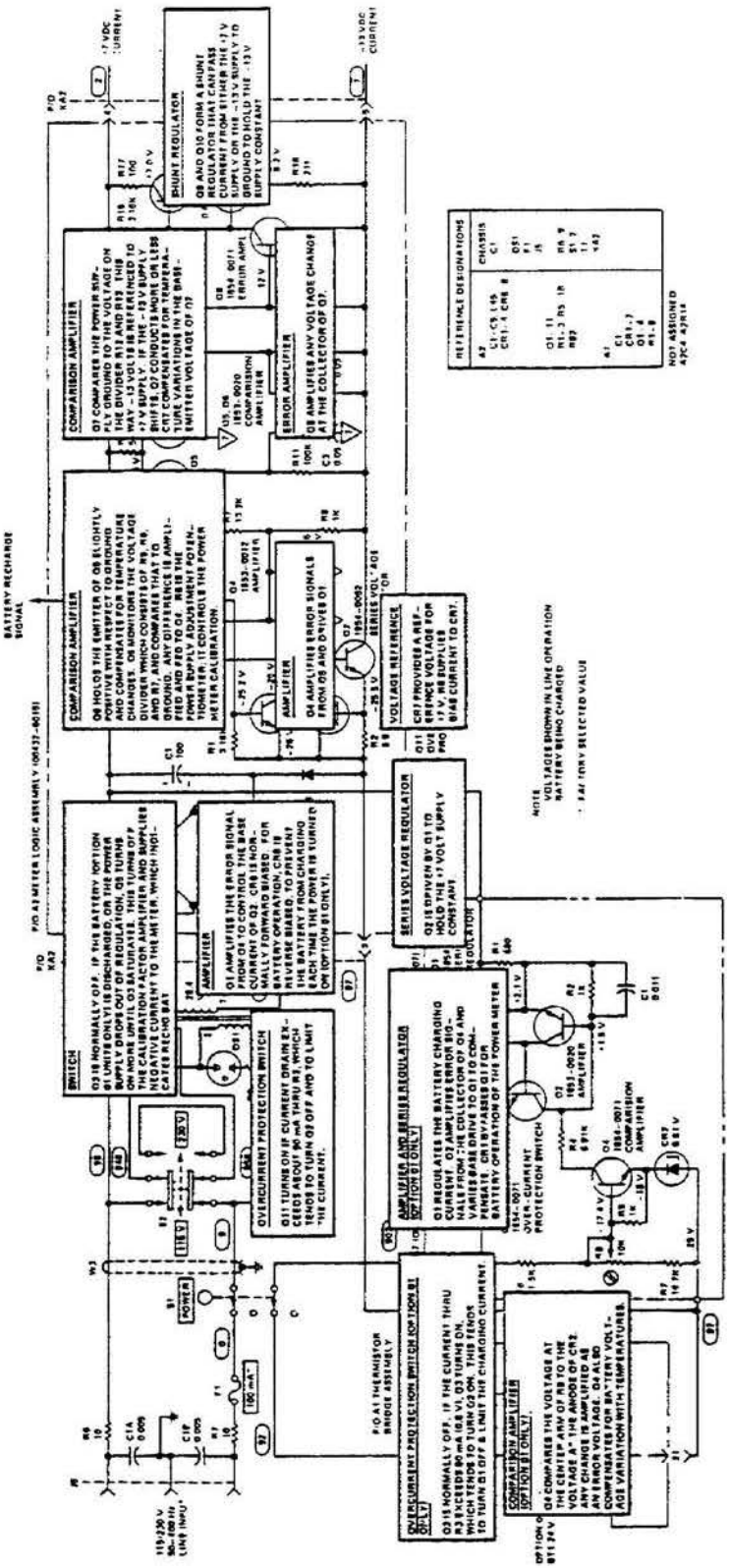


Figure 26B. Model 432A power supply talking schematic.

4. MODEL 478A THERMISTOR MOUNT.

a. Introduction.

(1) The thermistor mounts used with models 431C and 432A power meters are models 478A and 486 series. The description and specifications are covered in the following paragraphs.

(2) The 478A coaxial thermistor mount is designed for use with models 431 and 432 power meters to measure microwave power from 1 μW to 10 mW. Design of the mount minimizes adverse effects from environmental temperature changes during measurement. For increased measurement accuracy, Effective Efficiency and calibration factor are measured for each mount, and at selected frequencies across the operating range and the results are marked on the label of the instrument. The model 478A can be used over the 10 MHz to 10 GHz frequency range. Throughout the range, the mount terminates the coaxial input to 50 ohm impedance, and has a standing wave ratio of not more than 1.75 without external timing.

(3) Each mount contains two series pairs of thermistors which are matched to cancel the effects of drift with ambient temperature change. Thermal stability is accomplished by mounting the leads of all four thermistors on a common thermal conductor to ensure a common thermal environment. This conductor is thermally insulated from the main body of the mount so that thermal noise or shocks applied externally to the mount such as those from handling the mount manually, cannot significantly penetrate to disturb the thermistors. This manual immunity enables the thermistors to be used in the measurement of microwave power down to the microwatt region. See Table 5.

b. Precautions. Do not drop or subject to severe mechanical shock. Shock may destroy the match between thermistors and increase susceptibility to drift. When connecting the Model 478A to the 431 or 432 power meter, set the mount resistance switch to 200 ohm position. Connecting a 200 ohm mount to a power meter set for a 100 ohm mount can result in thermistor damage.

c. Maximum input. The model 478A/431 or 478A/432 combination responds to the average RF power applied. The maximum signal applied to the thermistor mount should not exceed the limitations for (1) average power (2) pulse energy and (3) peak pulse power. Excessive input can permanently damage the Model 478A by altering the match between the RF and compensation thermistors (resulting in excessive drift or zero shift) or cause error in indicated power.

d. Average Power. The 478A/431 or 478A/432 combination can measure average power up to 10 mW. To measure power in excess of 10 mW, insert a calibrated attenuator between the mount and the source. Under no circumstances apply more power than 30 mW to the mount.

Frequency Range: 478A: 10 MHz to 10 GHz

Mount Calibration: Calibration Factor and Effective Efficiency furnished at six frequencies between 10 MHz and 10 GHz.

Impedance: 50 ohms.

Maximum Reflection Coefficient:
10 to 25 MHz: 0.273 (1.75 SWR, 11.3 dB return loss).

25 MHz to 7 GHz: 0.13 (1.3 SWR, 17.7 dB return loss).

7 to 10 GHz: 0.2 (1.5 SWR, 14 dB return loss).

Operating Resistance: 200 ohms.

Power Range with Model 431 and 432A: 1 μW to 10 mW.

Elements: Field-replaceable, thermally balanced thermistor assembly. Thermistor assembly field adjustable so that full "zero-set" capability can be restored in the event of inadvertent overload (mount calibration no longer valid).

RF Connector: Type-N male. Brass connector.

Weight: Net, 5 oz (140 g). Shipping, 1 lb (460 g).

Uncertainty of Calibration Factor and Effective Efficiency Data for 478A

Sum of Uncertainties (%)			Probable Uncertainties (%)	
Freq. (GHz)	Cal. Factor	Effective Efficiency	Cal. Factor	Effective Efficiency
1.0	2.3	2.3	1.1	1.1
3.0	2.8	3.1	1.6	1.6
5.0	3.6	3.5	2.1	2.1
7.0	3.7	4.1	2.1	2.1
8.2	2.8	3.5	1.3	1.3
9.8	2.8	3.1	1.3	1.3
12.4	6.3	4.6	2.1	1.6
15.0	6.3	4.6	2.1	1.6
18.0	6.3	4.8	2.1	1.6

*Includes uncertainty of reference standard and transfer uncertainty. Directly traceable to NBS. In addition to the listed uncertainties, add the following for the indicated 431 ranges: ±0.3%; 0.1 mW, ±0.7%; 0.03 mW, ±1.5%; 0.01 mW. When using the 432 Power Meter no additional uncertainties are encountered.

Table 5. Specifications, model 478A.

e. Pulse Energy and Peak Power, for 478A/432 combination. For pulses shorter than 250 Aμ, energy per pulse must not exceed 10 W-μs and peak power should never exceed 200 watts, for example, a 40 mW, 250 μs pulse contains 10 W-μs of energy. Pulses longer than 250 μs are allowed to contain more energy but peak power must not exceed 200 W. Figures 27 and 28 interpret these limits in graphical form. The limitations given above are basically the same for 478A/431 combination with the exception that at pulse repetition rates less than 1 kHz, energy per pulse must not exceed 5 W-μs and peak power must not exceed 10 mW. These limits are also interpreted in Figures 1 and 2.

f. Square wave modulation is a special case of pulse modulation, and maximum power meter reading versus square wave frequency is illustrated in Figure 29. This figure also holds true for sine wave modulations.

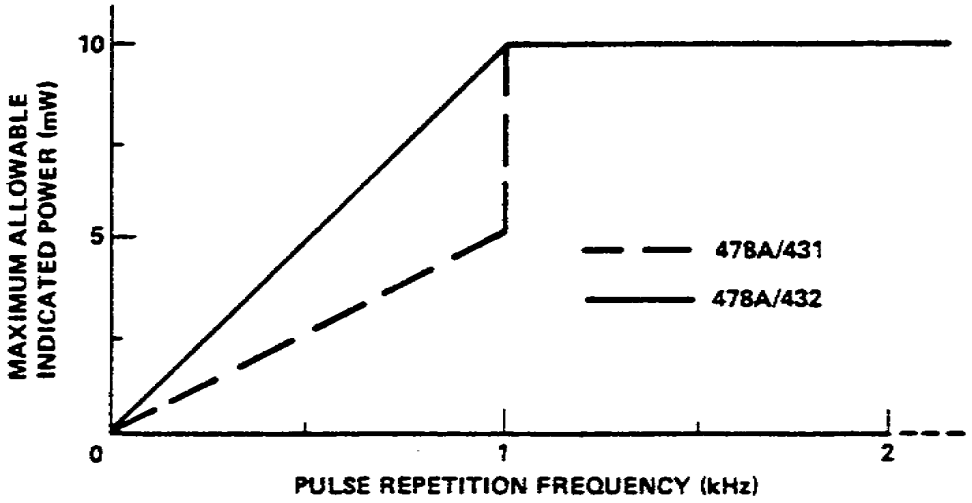


Figure 27. Maximum power meter reading versus PRF for pulses shorter than 250 µs.

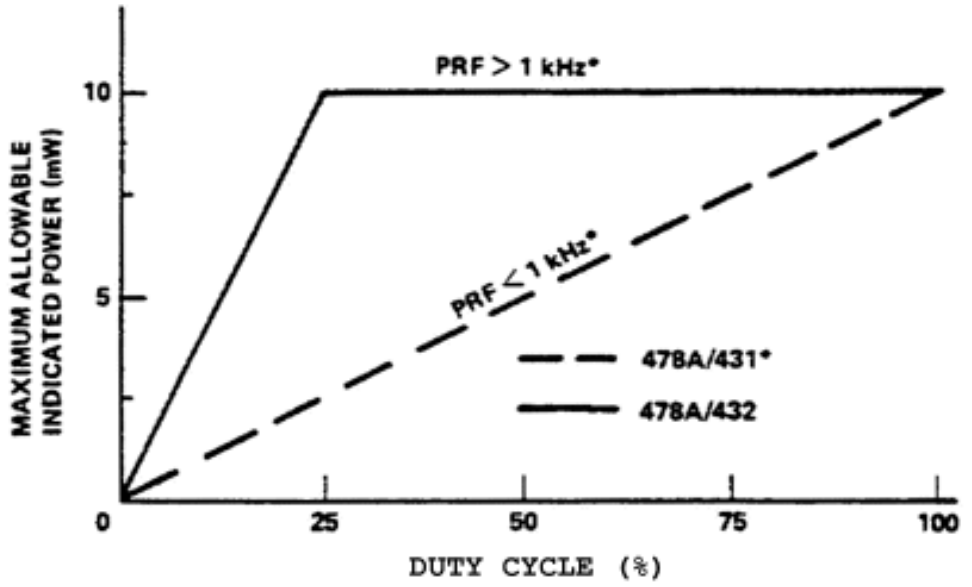


Figure 28. Maximum power meter readings versus duty cycle for pulses longer than 250 µs.

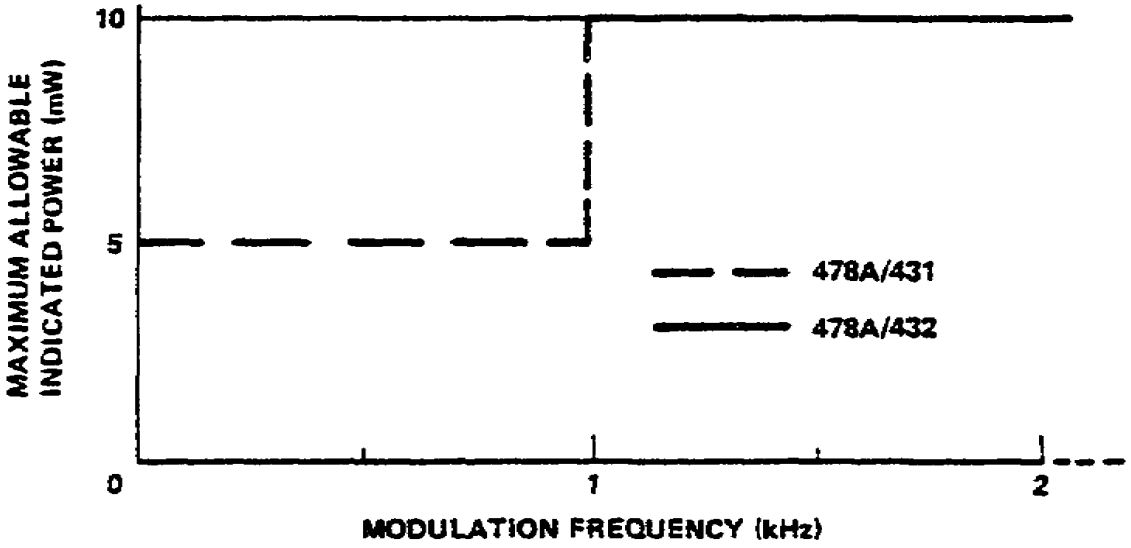


Figure 29. Maximum power meter reading versus square and sine-wave frequency.

g. In the discussions above, the primary consideration is maximum-power or energy. However, for modulation frequencies less than 100 Hz, the low repetition frequency itself causes errors in indicated power. These errors may be as large as 2% regardless of range or of reading.

h. Drift Precautions. Thermistors are inherently temperature sensitive devices. A cold thermistor mount connected to a warm piece of equipment, or vice-versa, produces rapid drift. For minimum drift on sensitive ranges, make sure that the mount and the equipment connected to it are at nearly the same temperature before making a measurement.

i. Operating principles.

(1) Two matched series thermistors are mounted on a common thermal conduction block, represented by the shaded rectangle in Figure 30, one pair, marked D for detection, is mounted between the end of a coaxial cable and a cylindrical cavity. These thermistors are exposed to incoming RF power which heats them, lowering their resistances. The other pair marked C for compensation and situated immediately outside the cavity is completely shielded from RF. With 478A attached to the 431 Power Meter, the detection thermistors are part of its metering circuit. With the 478A attached to the 432 Power Meter the detection thermistors are part of the RF bridge and the compensation thermistors are part of the compensation bridge. Since the two pairs of thermistors share the same thermal environment, any change in temperature which affects the rf bridge simultaneously affects the metering bridge, thereby allowing the power meter circuit to compensate for changes in temperature, and thus to minimize drift.

(2) During operation, sufficient amounts of DC and 10 kHz bias currents are supplied from the model 431 or 432 power meter to heat the thermistors until their resistances are reduced to approximately 200 ohms per series pair. Capacitor C1 offers high impedance to 10 kHz but is practically a short to RF. This causes D to appear series connected to 10 kHz, but parallel connected to RF. In this manner, D appears to the audio bridge of the model 431 or 432 power meter as a 200 ohm resistance but terminates the coaxial cable in 50 ohms. Capacitor C2 blocks any DC and audio power that may be present in the incoming signal, and passes only RF power. See Figure 30.

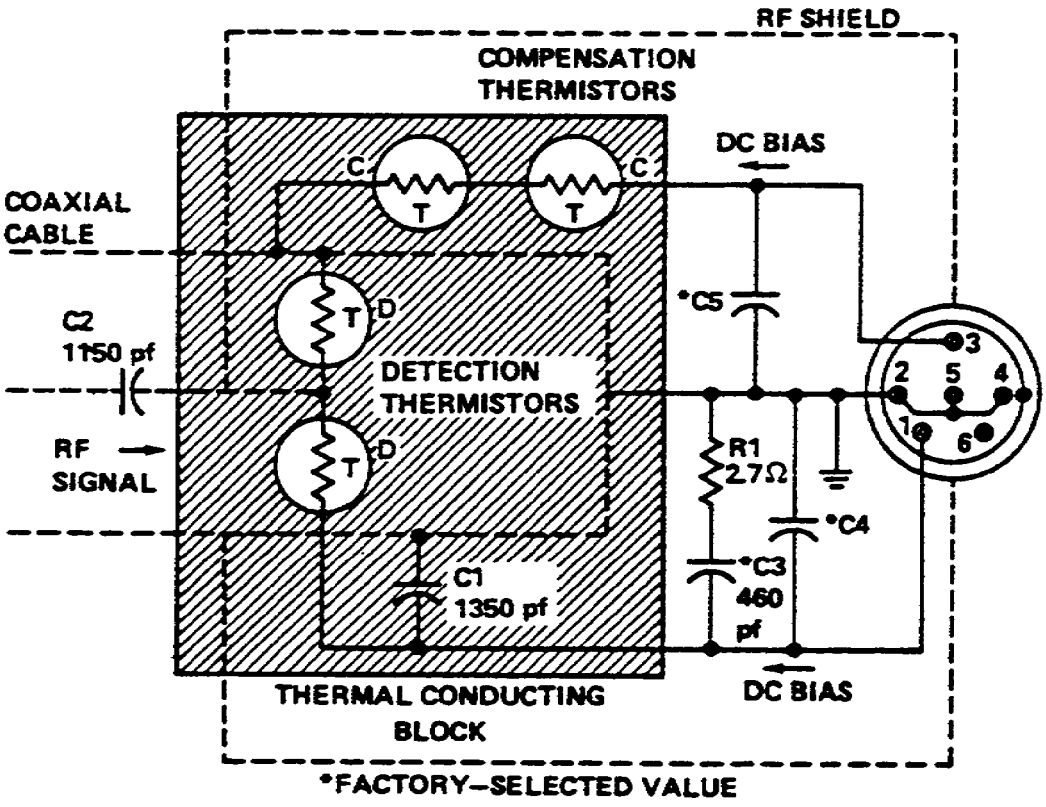


Figure 30. Schematic diagram of a model 478A thermistor mount when connected to a 432 power meter.

Model	Freq Range (GHz)	Max SWR	Operating Resistance (ohms)	Fits Waveguide Size Nominal OD (inches)	EIA	Equiv Flange JAN Type	Approx Length (inches)	(mm)	Net Weight (oz)	(g)
S486A	2.6 - 3.95	1.35	100	3 x 1-1/2	WR284	UG-53/U	2-7/8	74	24	670
G486A	3.95 - 5.85	1.5	100	2 x 1	WR187	UG-149A/U	3-9/32	83	11	310
J486A	5.3 - 8.2	1.5	100	1-1/2 x 3/4	WR137	UG-344/U	3-5/32	80	8-1/2	240
H486A	7.05 - 10.0	1.5	100	1-1/4 x 5/8	WR112	UG-51/U	2-3/4	70	5-1/4	150
X486A	8.2 - 12.4	1.5	100	1 x 1/2	WR90	UG-39/U	2-1/8	54	3	80
M486A	10.0 - 15.0	1.5	100	0.850 x 0.475	WR75		2-1/8	54	3-1/4	90
P486A	12.4 - 18.0	1.5	100	0.702 x 0.391	WR51	UG-419/U	2-3/8	60	3-1/4	90
K486A	18.0 - 26.5	2.0	200	1/2 x 1/4	WR42	UG-595/U	3	76	4-1/2	128
R486A	26.5 - 40.0	2.0	200	0.360 x 0.220	WR28	UG-599/U	3	76	4-1/2	128

Power Range: 1 µW to 10 mW.
Power Sensing Element: Permanently installed thermistor.
Output Connector: 6-pin connector mates with cable furnished with Power Meter.

Table 6. Specifications.

b. Precautions.

Mechanical Shock. DO NOT DROP OR SUBJECT TO SEVERE MECHANICAL SHOCK. SHOCK MAY DESTROY THE MATCH BETWEEN THERMISTORS AND INCREASE SUSCEPTIBILITY TO DRIFT.

CAUTION

Before connecting a 200 ohm thermistor mount (K or R486A) to a power meter, set MOUNT RES switch to 200 ohm position. CONNECTING A 200 OHM MOUNT TO A POWER METER SET FOR A 100-OHM MOUNT CAN RESULT IN THERMISTOR DAMAGE.

(3) Under normal operation, the total power supplied to heat thermistor pair D (see Figure 30) consists of: 1) RF signal, 2) 10 kHz bias and 3) heat from the environment. The total power supplied to heat thermistor pair C consists of: 1) DC bias, 2) an equal amount of 10 kHz bias, and 3) heat from the environment. As D and C are matched thermally, the total amounts of heat applied to reduce their series resistances equally must be equal.

5. MODEL 486A THERMISTOR MOUNT.

a. Introduction.

(1) Model 486A Thermistor Mounts are designed for use with Model 431 and 432 Power Meters in the measurement of microwave power from 1 µW to 10 mW in the range from 2.6 to 40.0 GHz. Design of power meter and thermistor mount is such that the measurement system is temperature-compensated. This feature permits microwave power measurements that are relatively free of the drift in meter indication that otherwise occurs with changes in ambient temperature. Table 6 lists the 486 series and their specifications.

(2) For improved accuracy of measurement results, Calibration Factor and Efficiency are measured at selected frequencies across the operating range of each mount, and the results recorded on the label of the mount. In addition, each mount is tested on a swept-frequency basis to assure that interpolation between measured points is valid.

NOTE

Do not remove polyfoam insert -- damage to the thermistor element may occur.

(3) Each Model 486A Mount is designed to provide a good impedance match (low SWR) over the full frequency range of its waveguide size without external tuning.

b. Maximum Input. The Model 486A/power meter combination responds to the average RF power applied. The maximum signal applied to the thermistor mount should not exceed the limitations for 1) average power, 2) pulse energy, and 3) peak pulse power. Excessive input can permanently damage the Model 486A by altering the match between the RF and compensation thermistors (resulting in excessive drift or zero shift) or cause error in indicated power.

c. Average Power. The 486A/Power Meter combination can measure average power up to 10 mW. To measure power in excess of 10 mW, a directional coupler (such as one of the Model 752 series) can be inserted between the mount and the source. UNDER NO CIRCUMSTANCES APPLY MORE THAN 15 mW AVERAGE TO THE MOUNT.

d. Pulse Energy and Peak Power.

(1) In measuring pulse power, there is a limit on the energy per pulse which may be applied to the mount. For a pulse repetition frequency (PRF) less than 1 kHz, energy per pulse can be up to 2.5 Watt-μsec; for a PRF 1 kHz and above, up to 4 Watt-μsec (for lack of space, only the lower limit is shown on the mount name plate). However, this energy limit applies only to pulses shorter than 250 μsec. In Figure 31, the pulse energy limit is translated into a maximum power-meter reading for any PRF. For pulses in this category, allowable peak power is inversely proportional to pulse width but should never exceed 100 Watts.

(2) For pulses longer than 250 μsec, the peak power limitation can be expressed in terms of PRF: 10 mW for a PRF below 1 kHz, 20 mW for a PRF 1 kHz or above provided 15 mW average is not exceeded. In Figure 32, the peak power limit is translated into power-meter reading versus duty cycle.

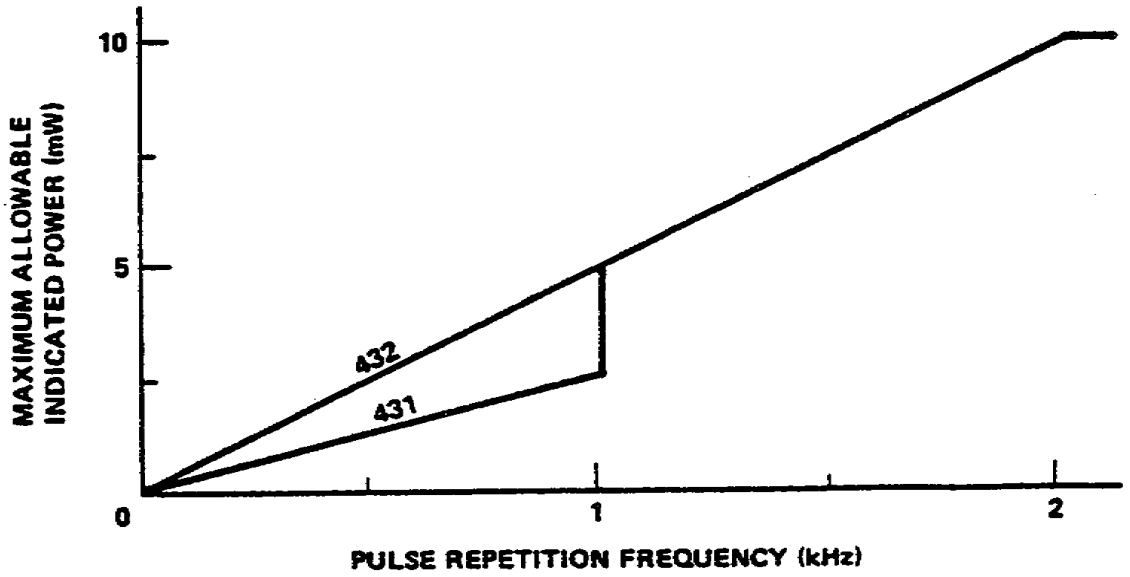


Figure 31. Maximum power meter reading versus PRF for pulses shorter than 250 µsec.

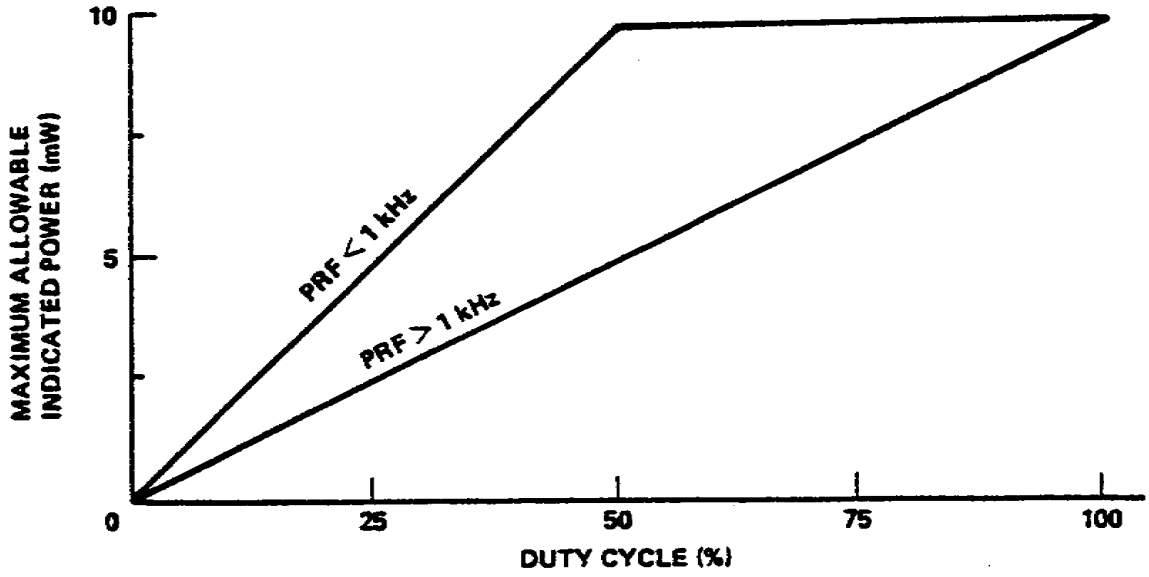


Figure 32. Maximum power meter reading versus duty cycle for pulses longer than 250 µsec.

Square-wave modulation is a special case of pulse modulation, and maximum power-meter reading versus square-wave frequency is illustrated in Figure 33. This figure also holds for sine-wave modulation.

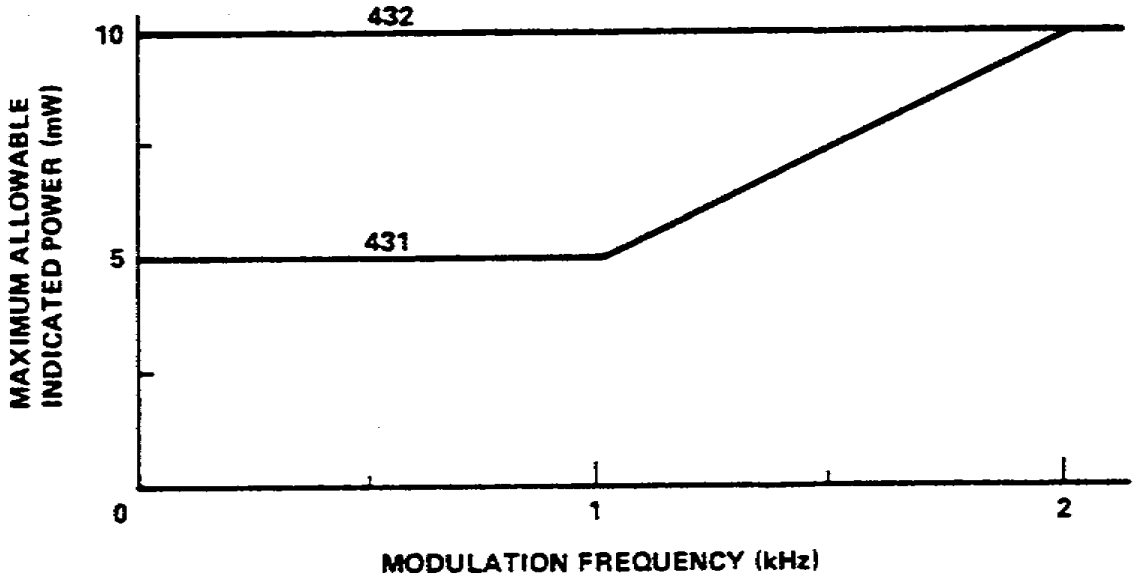


Figure 33. Maximum power meter reading versus square and sine-wave modulation frequency.

(3) In the discussions above, the primary consideration is maximum power or energy. However, for modulation frequencies less than 100 Hz, the low repetition frequency itself causes errors in indicated power. These errors may be as large as 2% regardless of range or reading.

f. Drift.

Thermistors are inherently temperature sensitive devices. A cold thermistor mount connected to a warm piece of equipment or vice-versa, produces rapid drift. FOR MINIMUM DRIFT ON SENSITIVE RANGES MAKE SURE THAT THE MOUNT AND THE EQUIPMENT CONNECTED TO IT ARE AT NEARLY THE SAME TEMPERATURE BEFORE MAKING A MEASUREMENT.

g. Zero-Set.

It is necessary to electrically zero-set the power meter before making a power measurement. To preserve the same zero reference through the measurement, especially when operating on the more sensitive ranges, maintain the same thermal environment when RF power is applied. Three recommended setups for zero-set are presented below:

(1) RF Power Turned Off. There is minimum zero drift when zero is set with the RF system connected to the thermistor mount and RF power turned off at the generator or shorted out by a shorting switch. After allowing time for the mount to stabilize thermally, follow the steps for zero-set described in the power meter manual, and then turn on the RF power for measurement.

(2) Use of High Attenuation with RF Source On. When it is inconvenient to turn off the RF source for zero-set, connect a waveguide variable attenuator, such as the Model 382A, between the RF system and the thermistor mount. Attenuate the RF power at least 30 dB for zero-set, and reduce attenuation to zero during the measurement.

(3) Disconnecting the Mount. When it is inconvenient to turn off or attenuate RF power, simply remove the mount from the source and, using COARSE and FINE ZERO, zero the power meter.

h. Power Measurement.

(1) The thermistor has a long thermal time constant, which causes it to respond to average microwave power whether CW or modulated (pulse, sine wave, or square wave).

(2) In pulse modulation, response is proportional to the amplitude and the duty cycle of the pulse. The power level of an individual pulse can be determined by dividing the average power reading by the duty cycle of the pulse. Accurate measurements can be made with pulse repetition rates as low as 50 Hz.

(3) To measure microwave power in excess of 10 mW insert a calibrated attenuator, such as one of the 382A, or 375A series, or a directional coupler, such as one of the 752 series, between the mount and the RF source to be measured.

CAUTION

Do not exceed maximum power rating of attenuator or directional coupler.

i. Mount Calibration Data.

(1) The calibration points imprinted on the label of each 486A allows power measurements to be made with increased accuracy. Values of Calibration Factor and Effective Efficiency are given at specific frequencies and the mounts are tested on a swept-frequency basis to assure accurate interpolation between calibration points. Calibration Factor and Effective Efficiency values are traceable to the National Bureau of Standards to the extent allowed by the Bureau's calibration facilities.

(2) Calibration Factor. Calibration Factor is the ratio of substituted audio or DC power in a thermistor mount to the microwave RF power incident upon the mount.

$$\text{Calibration Factor} \frac{P_{DC}\ \text{Substituted}}{P_{\mu\text{wave}}\ \text{Incident}}$$

Calibration Factor is a figure of merit assigned to a thermistor mount to correct for the following sources of error: 1) R^F reflected by the mount due to mismatch, 2) RF loss caused by absorption within the mount but not in the detection thermistor elements, and 3) DC-to-microwave power substitution error. Calibration Factor is applied as a connection factor to all measurements made without a tuner. When these factors and thermoelectric effect are taken into consideration, the power indicated is the power that would be delivered by the RF source to the characteristic impedance of the transmission line. The total SWR in the transmission line determines a region of uncertainty about the measured power.

(3) Effective Efficiency. Effective Efficiency is the ratio of substituted audio or DC power in a thermistor mount to the microwave RF power dissipated within the mount.

$$\text{Effective Efficiency} = \frac{P_{dc}\ \text{Substituted}}{P_{\mu\text{wave}}\ \text{Dissipated}}$$

Effective Efficiency corrects for power absorbed in parts of the mount other than the detection thermistor elements and DC-to-microwave power substitution error in the thermistor mount. Effective Efficiency is applied as a correction factor when a tuner is used to match the thermistor mount to the transmission line or RF source. In this case, all of the RF power incident upon the mount is absorbed in the mount, measurement uncertainty due to mount SWR is eliminated; however, losses in the tuner must be considered.

j. Calibration Data Application.

When the 486A is used with Model 431 or 432 Power Meters, Calibration Factor or Effective Efficiency corrections can be made by setting a front panel switch. With the proper setting, the 431 or 432 compensates for the Calibration Factor or Effective Efficiency in the 486A. If the 486A is used with a power meter other than the 431 or 432, Calibration Factor or Effective Efficiency corrections can be made by dividing the measured power by the Calibration Factor or Effective Efficiency value respectively.

k. Thermoelectric Effect Error.

The 432 Power Meter is not affected by thermoelectric effect error. However, the 431 Power Meter, which applies AC bias to the thermistors, is significantly affected: the magnitude of this error can be as high as 0.3 μW (0.1 μW typical). Thermoelectric effect error is important on the most sensitive ranges (.01, .03 and 0.1 mW) and when making DC substitution measurements. Refer to the 431 Power Meter manual for a procedure to measure the error and correct for it.

l. Operating Principles.

(1) The Thermistors.

The thermistors have a negative temperature coefficient; that is, when a thermistor's temperature increases, its resistance decreases. The 486A uses two thermistors: a detection thermistor that samples RF power and a compensation thermistor that compensates for ambient temperature changes. When the 486A is attached to a 432 Power Meter the detection thermistor (labeled D in Figure 34) is part of the RF bridge in the power meter; the compensation thermistor (labeled C in Figure 34) is part of the compensation bridge, and the bridges supply sufficient DC bias to drive the thermistors to their operating resistances (100 or 200 ohms).

(2) Detection Thermistor.

The detection thermistor is mounted within the mount's shorted waveguide section and is located so that it samples the E field and provides an optimum match across the band. As it absorbs RF power, its temperature (and therefore its resistance) attempts to change. However, the RF bridge circuit is self-balancing and reduces thermistor bias current to maintain the thermistor's proper operating resistance. Since the amount of bias change is proportional to incoming RF power, it is measured and used to in indicate the RF Power absorbed by the mount.

(3) Compensation Thermistor.

To prevent ambient temperature changes from affecting power readings, a compensation thermistor is mounted so that it shares the detection thermistor's thermal environment. Any change in ambient temperature causes a bias change in both thermistor bridges. This means that the total bias change in the detection thermistor is caused by incoming RF power plus ambient temperature. The power meter subtracts compensation bias from detection bias to get stable, error-free power readings.

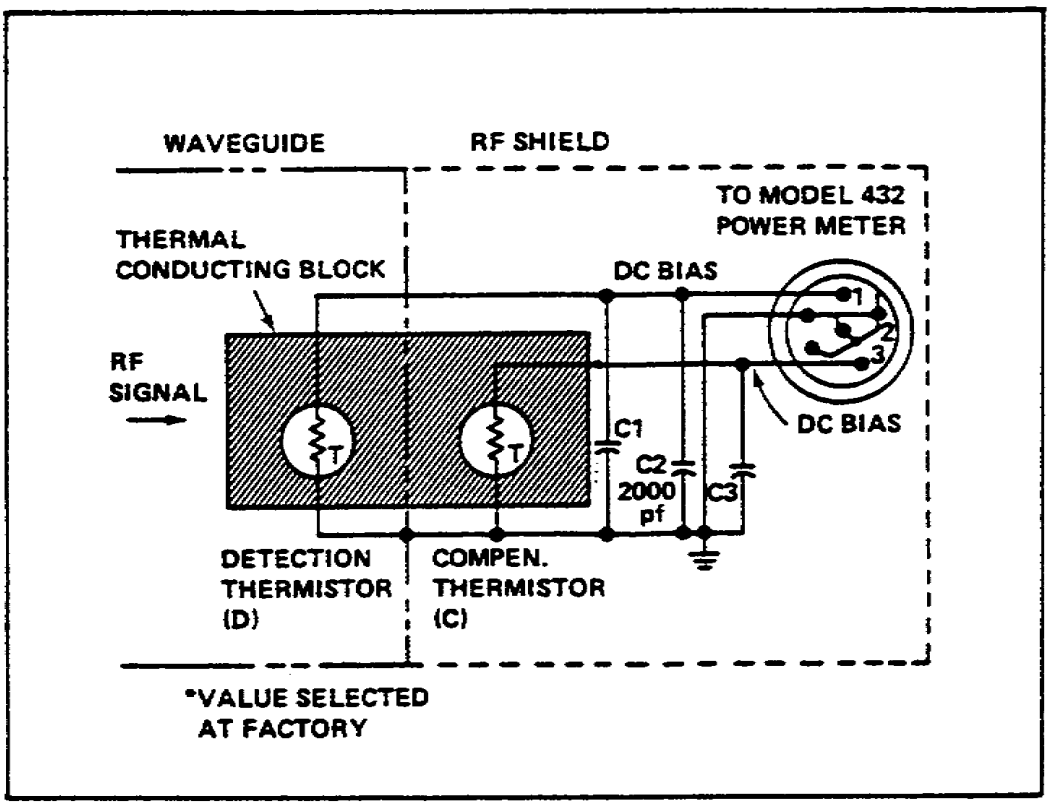


Figure 34. Thermistor mount schematic diagram.

m. Maintenance.

Except for the K and R Models, thermistor D (mounted inside the waveguide) is protected against air currents, dirt, and mechanical damage by two layers of polyfoam plastic. Polyfoam is soluable in most volatile solvents, such as gasoline, alcohol, benzene, carbon tetrachloride, acetone, etc., so great care should be used if one of these is used to clean the flange or inner surfaces of the waveguide. Use the plastic flange cover to protect the mount from direct and mechanical damage whenever it is not in use. Any burn, dents or dirt on the flange or waveguide surfaces will increase the SWR. This is particularly important in the case of the K486A and R486A, which do not have the polyfoam plastic protection.

AIPD SUBCOURSE NUMBER MM0474, POWER MEASUREMENTS

EXERCISES FOR LESSON 2

1. What output operates the meter circuit of the 431C Power Meter?

   A. 10 kHz bias from the oscillator amplifier
   B. DC output of the synchronous amplifier
   C. 10 kHz ground signal at the RF input

2. What position should the MOUNT RES switch on the front panel of power meter 431C be in, when using the model 8478B thermistor mount?

   A. 200 ohm Bal
   B. 200 ohm
   C. 100 ohm

3. What should be done to avoid severe damage to the thermistor mount while operating the RANGE switch?

   A. Zero adjust should not be moved
   B. Null adjust should not be moved
   C. Mount res switch should not be moved

4. The degree of inability of the instrument to measure the true substitution audio bias or DC power supplied to the thermistor mount is called

   A. DC-to-microwave substitution error.
   B. thermoelectric effect error.
   C. instrumentation error.

5. When both the RF source and the thermistor mount have the same impedance as the transmission line you have

   A. maximum transfer power.
   B. minimum transfer power.
   C. RF losses.

6. The amount of mismatch loss in any measurement depends on the

   A. available power.
   B. conjugate power.
   C. total SWR.

7. The effective efficiency concept corrects for

   A. calibration factor.
   B. thermistor mount inefficiency.
   C. thermistor mount efficiency.

8. What is used to reduce mismatch error when the source SWR is high or when high accuracy is required?

   A. Calibration factor
   B. Null adjust
   C. Tuner

9. Where is the calibration factor values of each thermistor mount obtained?

   A. From the power meter
   B. Data label of each mount
   C. Manufacturer's manual on the mount

10. What happens (in the power meter circuit) when the mount res switch, S1 is changed to match the thermistor mount used with it?

    A. Changes the resistance arm of the RF detection bridge
    B. Changes the bias to the thermistor mount
    C. Connects the RF detection bridge to the metering circuit

11. What is used to re-balance the loop in the compensation and metering bridge circuit of model 431C power meter?

    A. 10 kHz power
    B. DC feedback
    C. Compensating thermistors

12. What circuit in the model 431 power meter converts a linear voltage function, proportional to the square root of applied power, to a square function so that power may be indicated on a linear scale?

    A. Feedback differential amplifier
    B. Synchronous detector
    C. Meter circuit

13. When connected what effect does a recorder have on the panel meter of the Model 432A power meter?

    A. Decrease the meter reading by 10 dB
    B. Decrease the meter reading by half
    C. No effect on the panel meter

14. Power entering the thermistor mount but not dissipated in the detection thermistor element is called

    A. RF losses.
    B. instrumentation error.
    C. mismatch error.

15. How much impedance does the Model 478A thermistor mount terminate the input by?

    A. 35 ohms
    B. 50 ohms
    C. 75 ohms

16. The model 486A/power meter combination can measure average power up to 10 mW, how can power in excess of 10 mW be measured?

    A. Insert a tuner between mount and source
    B. Insert a directional coupler between mount and source
    C. Connect to thermistor mounts in series

17. Thermistor mount VSWR and RF losses is compensated by

    A. coarse zero control on power meter.
    B. mount resistance switch.
    C. calibration factor on power meter.

18. What is being accomplished on model 432A when the coarse and fine zero is adjusted?

    A. Adjusting V_{COMP} and V_{RFO}
    B. Adjusting V_{COMP} only
    C. Adjusting V_{RFO} only

19. What meter indication is made on the 432A power meter when the range switch is set to coarse zero?

    A. Thermistor mount unbalance
    B. Thermistor bridge balance
    C. Thermistor bridge unbalance

20. What is used to minimize mismatch between the source and the thermistor mount when a tuner is not used?

A. A termination
B. A low SWR precision attenuator
C. A directional couple

21. What indicates on the meter of the 431C power meter when the RANGE switch is in the null position?

A. Thermistor mount efficiency
B. Bridge balance
C. Bridge unbalance

22. The power a source will deliver to a load is called

A. available power.
B. conjugate power.
C. total power.

23. The instrumentation source of error can be reduced when making power measurements by using

A. a directional coupler between source and thermistor mount.
B. DC substitution method.
C. tuner.

24. Thermistor mount model 486A/power meter responds to the

A. peak-to-peak power.
B. peak RF power.
C. average RF power.

25. Thermoelectric effect error significantly affects

A. the 432 power meter.
B. the 431 power meter.
C. affects both the same.

LESSON 3. POWER MEASUREMENTS EQUIPMENT PART II

AIPD Subcourse Number MM0474.....Power measurements

Lesson Objective.....After studying this lesson you should be able to describe the circuits of the power meter calibrator and the principles of power meter calibration. You should also be able to answer the exercise questions without error.

Credit Hours.....Two

TEXT

1. INTRODUCTION.

a. The model 8402B Calibrator (Figure 1) is designed to be used with the entire series of 431 Power Meters. The model 8402B performs three basic functions: (1) verify full scale range calibration and meter tracking of the power meters; (2) measure the operating resistance of the RF detection thermistor elements used for power meter measurements; (3) provide a means to make DC substitution power measurements from 1 microwatt to 10 milliwatts.

b. Specifications of Calibration Functions.

(1) Calibration points: output currents corresponding to the following power levels for both 100 ohms and 200 ohms thermistor mount operation resistance: 0.01, 0.03, 0.1, 0.3, 1.0, 3.0, 10.0, 8.0, 6.0, 4.0, and 2.0 mW.

(2) Output current uncertainty: ±0.05%, 20° to 30°C; ±0.20%, 0° to 55°C.

(3) Overall power meter calibration uncertainty: 2X current uncertainty ± thermistor operating resistance uncertainty (±0.16%, 20° to 30°C, ±0.46%, 0° to ±55°C).

(4) Thermistor operating resistance function, resistance center values: 100 and 200 ohms. Range: ±0.5% about center values, adjustable in 0.1% steps. Uncertainty: thermistor operating resistance can be determined within ±0.06%.

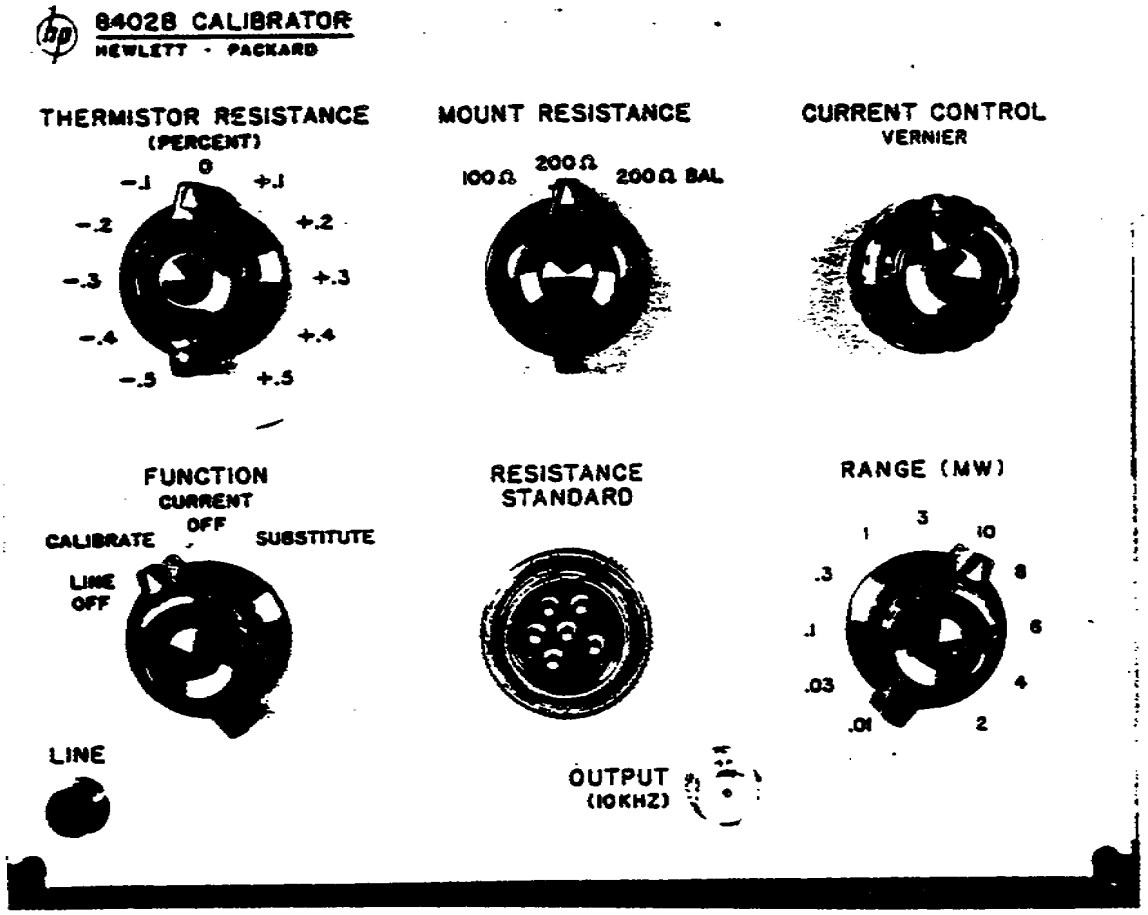


Figure 1. Model 8402B, front panel.

c. DC Substitution Function.

(1) Range: Current variable over a range compatible with measurements from 1 mW to 10 mW (precision differential or digital voltmeter required, voltmeter input resistance greater than 10 megohms is required for negligible loading effect).

(2) Uncertainty ± (0.06% + thermistor operating resistance uncertainty + 2X voltmeter uncertainty) 0 to 55°C.

(3) Voltmeter output: Dual banana connector on rear panel for monitoring voltage across precision resistors.

d. Power Requirements. The model 8402B is operated from an AC power source of either 115V or 230V, 50 to 400 Hz.

CAUTION

For AC operation, set the rear-panel 115V-230V switch to the proper position before connecting the power cord to the service outlet.

2. GENERAL.

a. This section presents the basic information required to operate the Model 8402B Calibrator.

b. The 8402B is an accurate source of DC power. DC power output is continuously variable or can be set to 431C full-scale range levels with front panel controls. Variable output current control permits DC substitution power measurement with the 431C, from 1 μW to 10 mW. These power levels are used to check calibration accuracy of the 431C. In addition, power levels of 8.0, 6.0, 4.0, and 2.0 mW can be selected to check power meter tracking accuracy.

c. The operating resistance of the RF detection thermistor element used on a 431C power measurement can be accurately determined using the 8402B. The front panel RESISTANCE STANDARD jack connects precision resistance circuits to the RF detection bridge in the 431C Power Meter. By rotating the front panel switch, the meter on the 431C is used to indicate the position of the switch at which normal operation circuit conditions exist. Thermistor mount resistance error is determined using the MOUNT RESISTANCE switch.

3. CONTROLS, CONNECTORS, AND INDICATORS.

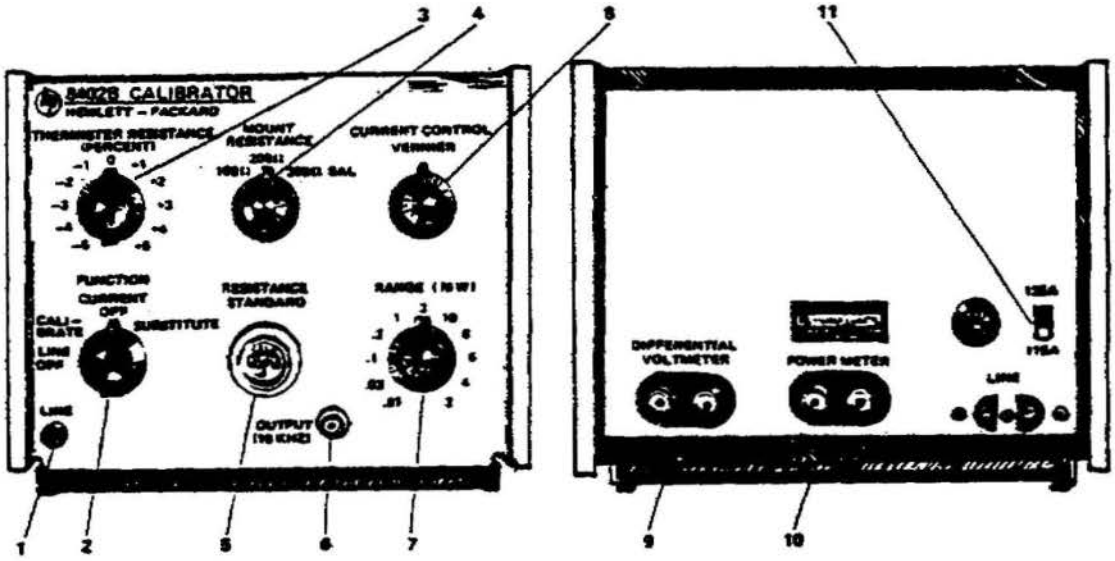
The front and rear panel controls, connectors, and indicators are explained in Figure 2. The descriptions are keyed to the corresponding items which are indicated on the figure. Further information regarding the various settings and uses of the controls, connectors, and indicators is included in the following paragraphs of this lesson.

4. OPERATING INFORMATION.

Refer to Figure 3 for step-by-step instructions for operating the 8402B. A procedure for measuring the operating resistance of the RF detection thermistor element is included as part of the DC substitution procedure. Instructions for using the 8402B to check 431C calibration and meter tracking accuracy are given in Paragraph 6.

5. DC SUBSTITUTION.

a. Power meter instrumentation error can be reduced by using DC substitution. With precision instruments used in a DC substitution



Note

Observe power meter polarity (Red to Red).

1. LINE. Lamp lights when instrument is on: FUNCTION switch set to CALIBRATE, CURRENT OFF, or SUBSTITUTE.

2. FUNCTION. Controls primary line power and selects fixed or variable internal voltage reference.

   LINE OFF: Instrument off.

   CALIBRATE: Fixed internal voltage reference. CURRENT CONTROL and VERNIER controls do not vary DC output.

   CURRENT OFF: Instrument on. Zero DC output.

   SUBSTITUTE: Variable internal voltage reference. CURRENT CONTROL and VERNIER controls vary DC output.

3. THERMISTOR RESISTANCE (PERCENT). Determines deviation of RF detection thermistor resistance from nominal operating value. Sets resistance at RESISTANCE STANDARD connector.

4. MOUNT RESISTANCE. Provides identical power levels to thermistor operating resistances of 100 ohm, 200 ohm, and 200 ohm balanced configuration.

5. RESISTANCE STANDARD. Accepts thermistor mount cable from 431C Power Meter.

6. OUTPUT (10 kHz). Provides a connection to the 10 kHz audio bias lead in the thermistor mount cable.

7. RANGE (MW). Sets output power levels that correspond to 431C Power Meter ranges.

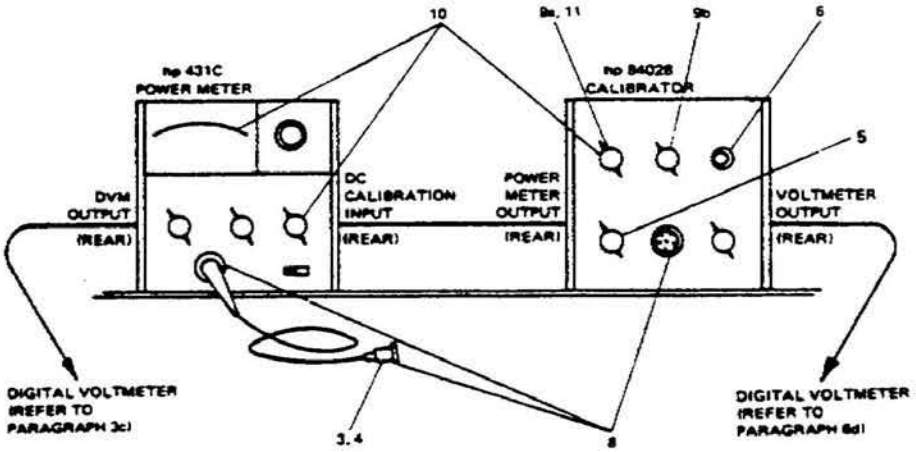
8. CURRENT CONTROL and VERNIER. With FUNCTION switch set at SUBSTITUTE, these controls vary the DC output.

9. DIFFERENTIAL VOLTMETER. Provides a DC voltage proportional to the DC output. Refer to Paragraph 6.d.

10. POWER METER. Provides a DC output to the 431C Power Meter.

11. LINE VOLTAGE. Selects 115- or 230-volt line operation.

Figure 2. Front and rear panel controls, connectors and indicators.



1. Connect the equipment shown above. DC substitution is discussed in Paragraphs 6.a through 6.i.

2. Set the 431C Power Meter for normal operation using the procedure given in Figure 3-8.

3. Set CALIBRATION FACTOR to agree with Calibration Factor or Effective Efficiency data on mount (see Paragraph 3-32). Apply RF power to mount. Note reading obtained on digital voltmeter.

   Note

   If the .01, .1, 1, or 10 mW power meter ranges are used, the digital voltmeter reads directly. If the .03, .3, or 3 mW power meter ranges are used, the digital voltmeter reading must be multiplied by .0316, .316, or 3.16, respectively.

4. Turn off, or disconnect, the RF source.

5. Turn on 8402B Calibrator by setting the FUNCTION switch to CURRENT OFF; then apply a substitution current by setting FUNCTION switch to SUBSTITUTE.

6. Set CALIBRATION FACTOR to 100%. Turn 8402B CURRENT CONTROL and VERNIER to duplicate reading obtained in step 3.

7. Note 8402B VOLTMETER output DVM reading. On .01, .03, .1 and .3 mW ranges, reading is substituted current (I_{DC}) in mA. On other ranges multiply reading by 10 to obtain I_{DC} in mA.

8. Disconnect thermistor mount from thermistor mount cable. Connect thermistor mount cable between 431C Power Meter THERMISTOR MOUNT and 8402B Calibrator RESISTANCE STANDARD connectors.

9. Set 8402B Calibrator controls as follows:

   a. THERMISTOR RESISTANCE . . . . +0.5%.

   b. MOUNT RESISTANCE to correspond with resistance and type of thermistor mount used.

10. Set 431C Power Meter RANGE switch to NULL. Rotate THERMISTOR RESISTANCE switch on 8402B Calibrator counterclockwise until the 431C Power Meter changes to a zero reading from a stable reading greater than zero.

11. The operating resistance of the detection thermistor (R_d) is the nominal value indicated on the thermistor mount label plus or minus the correction indicated by the setting of the THERMISTOR RESISTANCE switch. The percentage correction is a value in-between the limits set by the two positions of the THERMISTOR RESISTANCE switch that correspond to the zero reading and the stable meter reading obtained in step 10. If desired, the average of these two values may be calculated and used as the correction value.

12. Calculate power in mW from the following expression:

$$\text{Power (mW)} = \frac{(I_{DC})^2 (R_d) (10^{-3})}{4}$$

Where:

I_{DC} = Substitution current in mA (from step 7)

R_d = Operating resistance of the detection thermistor (from step 11)

Figure 3. DC substitution and thermistor operating resistance measurement.

setup, and careful procedure, 431C instrument error can be reduced from ±1% of full scale to ±0.16% of reading, or less. The technique involves: applying the RF power to be measured to the thermistor mount and noting the power meter reading removing the RF power from the thermistor mount and substituting a DC current from an external DC power source to duplicate precisely the power from the substituted DC current and thermistor operating resistance.

b. Equipment Used for DC Substitution. Figure 3 shows the instrument setup for a DC substitution measurement. The 8402B Calibrator provides DC power and appropriate switching to perform DC substitution measurements with the Model 431C.

c. Although the DC substitution technique is the most accurate method of measuring RF power, there are sources of error that must be considered. The accuracy of DC substitution depends largely upon: substitution voltage accuracy, how precisely the power meter reading is duplicated, the actual operating resistance of the thermistor.

d. DC Substitution Accuracy. The DIFFERENTIAL VOLTMETER jack on the rear panel is used to monitor the calibrator output current. Voltage present at the jack is directly proportional to the substituted current. To determine the uncertainty of substitution measurements, the following factors must be accounted for:

(1) Uncertainty of the thermistor mount operating resistance: can be measured to ±0.06% with the calibrator internal resistance standard.

(2) Tolerance of resistor across which the voltage is measured: ±0.01%.

(3) Accuracy of the voltmeter used for the measurement: ±0.005% of reading, +0.0004% of range, +1 μV when using a DC VOLTMETER STANDARD.

(4) Differential voltmeters do not load the output voltage; loading effect on the output voltage when using a digital voltmeter must be accounted for. Input impedance mast be 10 megohms or greater on the 1.0 to 10 mW ranges, and 100 megohms or greater on the lower ranges of the calibrator for negligible loading of less than 0.001%.

(5) Twice the voltage uncertainty equals the power uncertainty introduced by the voltmeter.

e. The DIFFERENTIAL VOLTMETER jack output impedance is finite. The impedance is 100 ohms on the 1.0 through 10 mW ranges, and 1 kilohm on the lower ranges. At null, a differential voltmeter draws no current from the calibrator voltage output and therefore does not cause a loading error. When using other types of voltmeters, the effect of loading must be accounted for. For example, a digital voltmeter with an input

impedance of 1 megohm introduces a measurement error of 0.1% on ranges below 1.0 mW. Twice this error is the power measurement error: 0.2%. This error must be added to the power measurement to correct the reading.

f. Calibrator accuracy specifications are ±0.05%. If the measurement uncertainty is determined to ±0.02%, a ±0.03% leeway remains in the calibration of the instrument. The closer the instrument can calibrate to a standard, the better the calibration of power meters may be performed. Calibration of the precision resistors in the RESISTANCE STANDARD switch circuitry is best done using standards laboratory techniques to ensure minimization of measurement uncertainty.

g. Power Meter DVM Output Measurement. A digital voltmeter can be connected to the 431C Power Meter DVM jack to increase resolution of a power meter reading and allows an easy method of repeating a precise measurement readout value. Measurement error corrections for voltmeter impedance loading must be made when using a voltmeter to measure the voltage output of the 431C Power Meter. The DC voltage at the DVM connector on the rear panel is developed across a 1 k ohm resistor. Therefore, a voltage measurement made with a digital voltmeter having an input impedance of 500 k ohms will introduce an error of 0.2%. A digital voltmeter with an input impedance of 10 megohms will introduce a much smaller error of 0.01%. Correction percentages should be added to voltmeter readings. If the .01, .1, 1 or 10 mW power meter ranges are used, the digital voltmeter reads directly. If the .03, .3, or 3 mW power meter ranges are used, the digital voltmeter reading must be multiplied by . 0316, .316, or 3.16, respectively.

h. Detection Thermistor Resistance. Steps 8 through 11 of Figure 3 list a procedure to determine the operating resistance of the 431C Power Meter RF detection bridge at balance, and thus measure the operating resistance of the detection thermistor element (R_d) during a power measurement.

NOTE

The actual operating resistance of detection thermistors may deviate as much as ±0.5% from their nominal values. For this reason, the actual operating resistance should be checked so that the substituted DC power in a DC substitution measurement can be calculated accurately.

i. The 8402B provides a convenient method of determining the detection thermistor operating resistance. The thermistor mount cable is connected between the 431C Power Meter THERMISTOR MOUNT and 8402B Calibrator RESISTANCE STANDARD connectors. By the THERMISTOR RESISTANCE switch, the 8402B Calibrator substitutes precision resistance values in place of the thermistor elements normally in the 431C bridge circuits. The switched resistances provide a method of determining oscillator/non-oscillation states of the 431C Power Meter.

j. With the 431C RANGE switch at NULL, a stable reading greater than zero indicates an audio-bias oscillation state. While changing the substituted resistances, the operator can determine when oscillations cease by noting a change of meter readings to zero. The operating resistance of the detection thermistor element is measured by reading the resistance deviation in percent directly from the switch settings that cause the power meter to change from an oscillation to a non-oscillation state.

6. PRINCIPLES OF OPERATION.

a. Overall Description.

(1) The block diagram of the 8402B is shown in Figure 4. The 8402B precision DC generator circuit consists of a differential amplifier and two output transistors connected in a Darlington-combination. Eleven switchable power ranges are selected by precision resistances in the emitter circuit of the output transistors. The differential amplifier may be switched to either of two types of internal voltage references. Both voltage references are furnished -30 volts by a regulated power supply. One voltage reference is fixed and the other is continuously variable. The fixed voltage reference is used in the CALIBRATION mode of operation, the variable voltage reference is used in the SUBSTITUTE mode. The variable voltage reference is used to provide an adjustable DC power output, over the power range selected, for DC substitution power measurements made with a 431C Power Meter. A voltmeter output provides a DC voltage proportional to the output current.

(2) The thermistor resistance function circuit of the 8402B is passive. Precision resistances are substituted for the RF detection thermistor in the 431C Power Meter RF detection bridge. The power meter is used to indicate the bridge balance condition identical to chat during an actual power measurement. This indication provides a means to measure the RF detection thermistor operating resistance.

b. Precision Current Generator.

(1) The schematic diagram of the 8402B is shown in Figure 5. The precision DC generator consists of transistors A1Q8A thru A1Q7 and associated circuits. Transistors A1Q8A and 8B form a differential amplifier. The circuit loop from the collector of A1Q8B thru the base and emitter of A1Q6, and the base and emitter of A1Q7, returning to the base of A1Q8B is a negative feedback loop of moderate loop gain. The function of the loop is to maintain the voltage at the base of A1Q8B equal to the voltage at the base of A1Q8A. The voltage at the base of A1Q8A is a reference voltage that is derived from one of two sources, depending on the mode of operation. In the CALIBRATE mode, a fixed reference voltage is precisely developed across the temperature-compensated breakdown diode pair, A1VR2. In the SUBSTITUTE mode, the reference is continuously variable by the CURRENT CONTROL AND VERNIER controls.

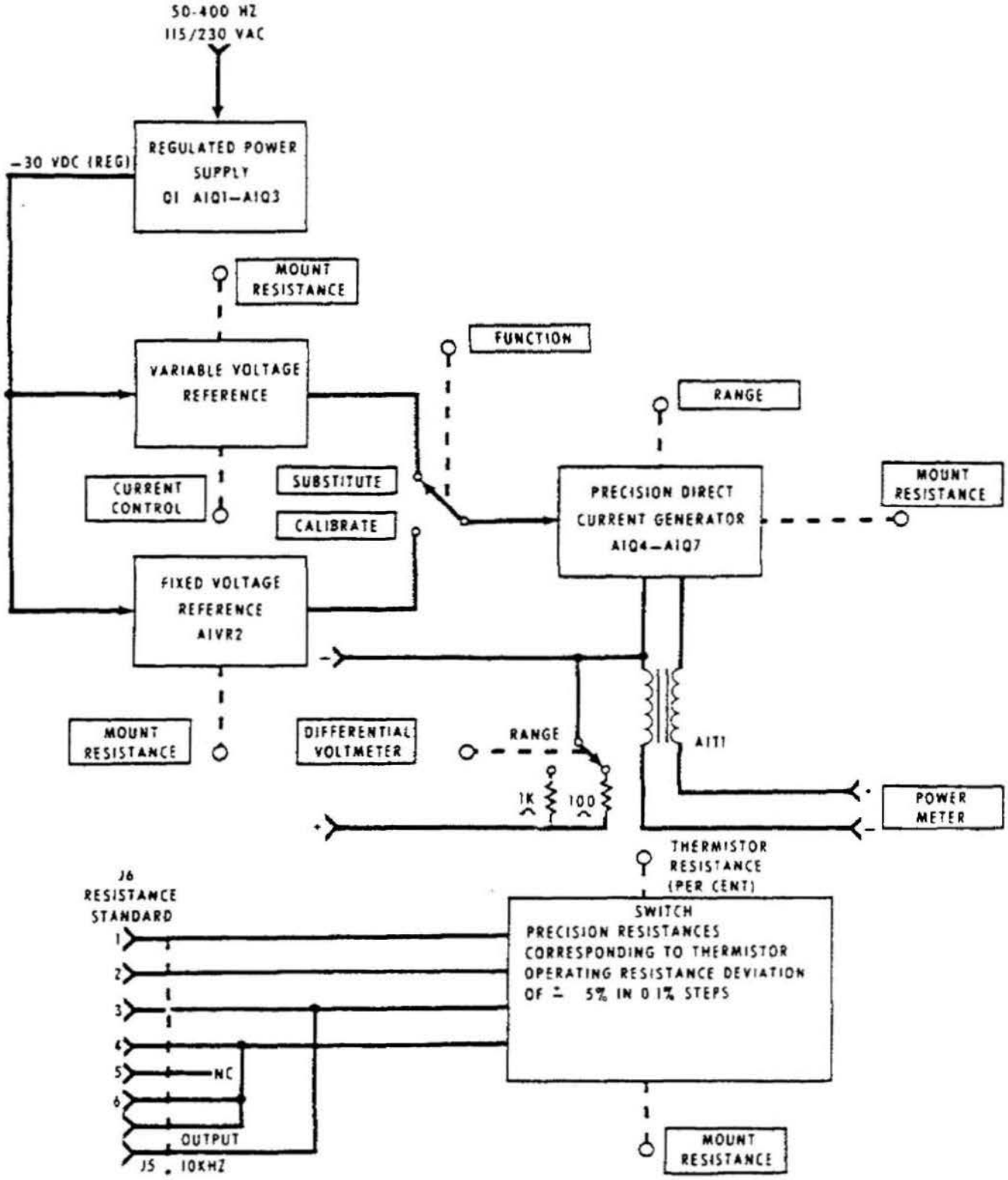


Figure 4. Block diagram, model 8402B calibrator.

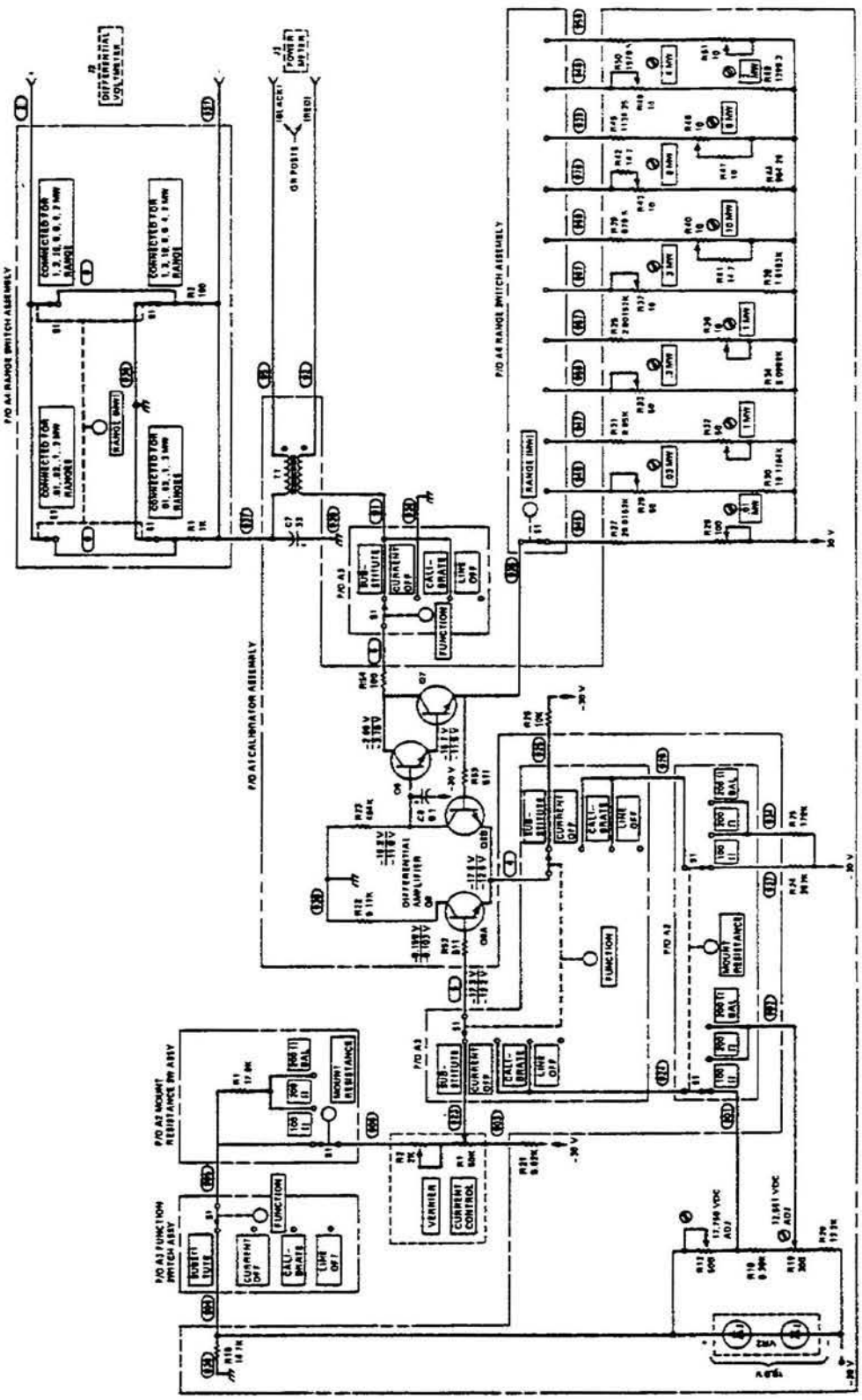


Figure 5. Schematic diagram, model 8402B calibrator.

(2) The voltage at the base of A1Q8B determines the current output to the POWER METER jack. This voltage is developed across a precision resistance selected by the RANGE switch. The RANGE switching circuit consists of 11 precision wire-wound resistors, each padded by an adjustable potentiometer (resistors A1R27 through A1R51). Since each resistance can be set precisely by an individual pad potentiometer, the current through any selected resistance is known to a great degree of precision. The current at the POWER METER output is carefully controlled to be the same as the current through the selected range resistance. The Darlington-combination of transistors A1Q6 and A1Q7 results in a high forward current gain. This gain minimizes any noncancellation effects of current flowing from the collector of A1Q8B to the base of A1Q6 and the current flowing from the emitter of A1Q7 to the base of A1Q8B.

(3) The voltage necessary at the base of A1Q8B to generate the range currents for a 100 ohm thermistor mount is 17.750 volts. The corresponding voltage for a 200 ohm mount is 12.551 volts. Both voltages are positive with respect to the -30 VDC power supply voltage. Division of voltage for the two mount operating resistances is accomplished by A1R17 (17.750 VDC ADJUST), A1R18, and A1R19 (12.551 VDC ADJUST).

(4) When the 431C Power Meter is used with a 100 ohm balanced thermistor mount, 10 kHz bias signal appears at the Calibrator POWER METER connection. Transformer A1T1 presents a high impedance to the 10 kHz signal, thus preventing interaction between it and the calibrator circuit.

c. Regulated Power Supply.

(1) The power supply schematic is shown in Figure 6. The power supply circuit consists of a full-wave bridge, A1CR1 through A1CR4, series regulator Q1, emitter follower A1Q1, differential amplifier A1Q2-A1Q3, and associated circuits. Initial filtering of the negative rectified voltage is accomplished by C1 and the voltage is isolated from chassis ground by C2. The negative voltage is presented to the series regulator, Q1. The series regulator is referenced to a common ground by a temperature-compensated Zener diode, A1VR1. A balanced differential amplifier, A1Q2-A1Q3, is used to compare the regulated output voltage to the Zener reference. Current for the Zener reference diode is taken from the regulated -30 volt side of the power supply.

(2) For explanation, assume that diode A1CR6 is removed from the circuit and an open circuit is substituted in its place. When the power supply is turned on, both the reference voltage at the base of A1Q2 portion of the differential amplifier and the power supply output voltage are zero. A zero potential at the bases of the differential amplifier transistors A1Q2-A1Q3 prevents them and both the emitter follower, A1Q1, and the series regulator, Q1, from conducting. In this state, the power supply is stable with an output voltage of zero. Now

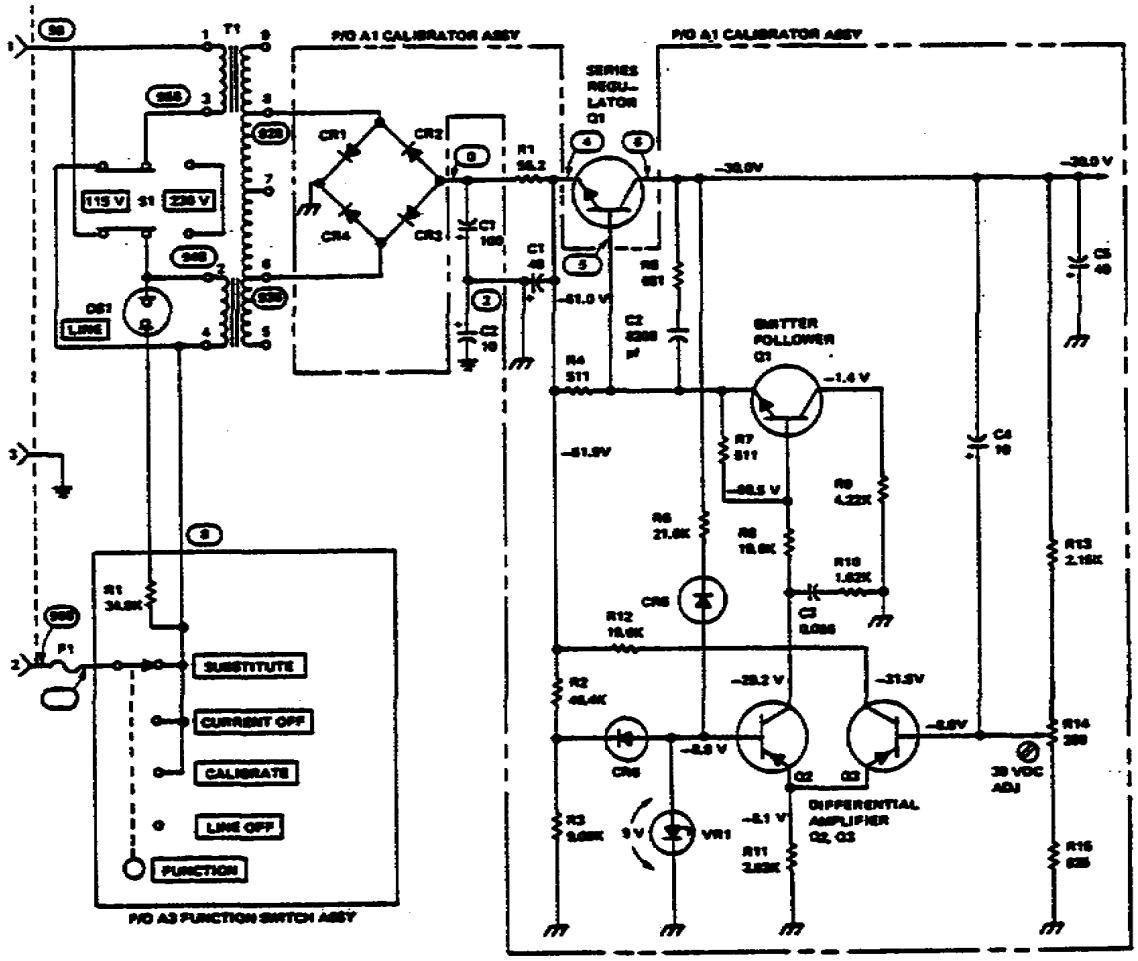


Figure 6. Power supply schematic.

consider A1CR6 to be placed back in the circuit. The purpose of A1CR6 is to initially provide a negative voltage at the base of A1Q2. When the power supply is turned on, a negative voltage appears at the junction of A1R2 and A1R3. The negative voltage forward biases A1CR6 and allows it to conduct. Thus, the negative voltage is applied to the base of A1Q2, allowing it to conduct. In turn, the base-emitter junction of the emitter follower, A1Q1, is forward biased and it also conducts. This action forward biases the base-emitter junction of the series regulator, Q1, which conducts, causing its collector voltage to increase negatively toward -30 volts. This action places more negative voltage on the cathode of A1CR5 causing it to conduct. Conduction of A1CR5 supplies an increasingly negative voltage to the base of A1Q2. This process is regenerative and the base voltage of A1Q2 continues to increase negatively until it is held at -9 volts by A1VR1.

(3) To achieve -30 volts at the start of the regenerative process, A1CR5 is reverse biased by the negative voltage placed on its anode by the conduction of A1CR6. Diode A1CR5 is reverse biased at this time so that all the current from A1R2 and A1R3 is routed through the base of A1Q2 portion of the differential amplifier instead of through A1R6. After the power supply reaches -30 volts, the biases on A1CR5 and A1CR6 are reversed. Diode A1CR5 is forward biased by the greater negative potential from the output of the series regulator with respect to its anode voltage -9 volts from A1VR1. Diode A1CR6 is reverse biased by a relative negative potential on its anode by -9 volts from A1VR1 with respect to the negative voltage at the junction of A1R2 and A1R3. With these final circuit conditions, the current through A1VR1 is derived from the output of the series regulator Q1. The action of the differential amplifier A1Q2-A1Q3 stabilizes the output voltage of the series regulator at the level necessary to supply -9 volts to the base of A1Q3. The output of the power supply is set at -30 volts by adjusting A1R14 to provide exactly -9 volts to the base of A1Q3 portion of the differential amplifier.

d. Thermistor Resistance Function.

(1) Thermistor Resistance Function is shown in the schematic in Figure 7. The purpose of this function is to determine the exact operating resistance of a RF detection thermistor element when used with a 431C Power Meter for microwave power measurement. During an actual power measurement, the RF detection thermistor element resistance is determined by the application of 10 kHz audio bias power from the poker meter. The audio bias magnitude is dependent on the amount of detection bridge unbalance. At balance, the thermistor resistance is made nearly equal to the balancing resistance arm of the bridge. However, this operating resistance may not be exactly the nominal operating resistance imprinted on the thermistor mount label. The actual operating resistance of the detection thermistor element may deviate as much as ±0.5% from the nominal value. The thermistor resistance function of the 8402B measures this deviation by measuring the balancing resistance arm of the 431C detection bridge network under simulated operating conditions.

(2) The thermistor resistance function circuit is entirely passive. Resistive circuits connected to the RESISTANCE STANDARD connector, J4, appear as a thermistor mount to the RF detection bridge network. However, instead of heat sensitive thermistors as the resistive elements, precision 0.01% resistors are used. The substituted resistance values are determined by the THERMISTOR RESISTANCE (PERCENT) switch. The resistors are designated A5R1 through A5R10, plus an infinite resistance for the ±0.5% position of the switch. Resistance values placed in the 431C RF detection bridge network determine the feedback loop gain of the bridge 10 kHz amplifier combination in the power meter. If the resistance substituted for the thermistor is less than the balancing resistance arm of the bridge, the loop gain is less than unity since feedback is negative. If the substituted resistance is greater than the balancing resistance, the loop gain is greater than unity since feedback is positive. These two conditions result in a no-oscillation/oscillation

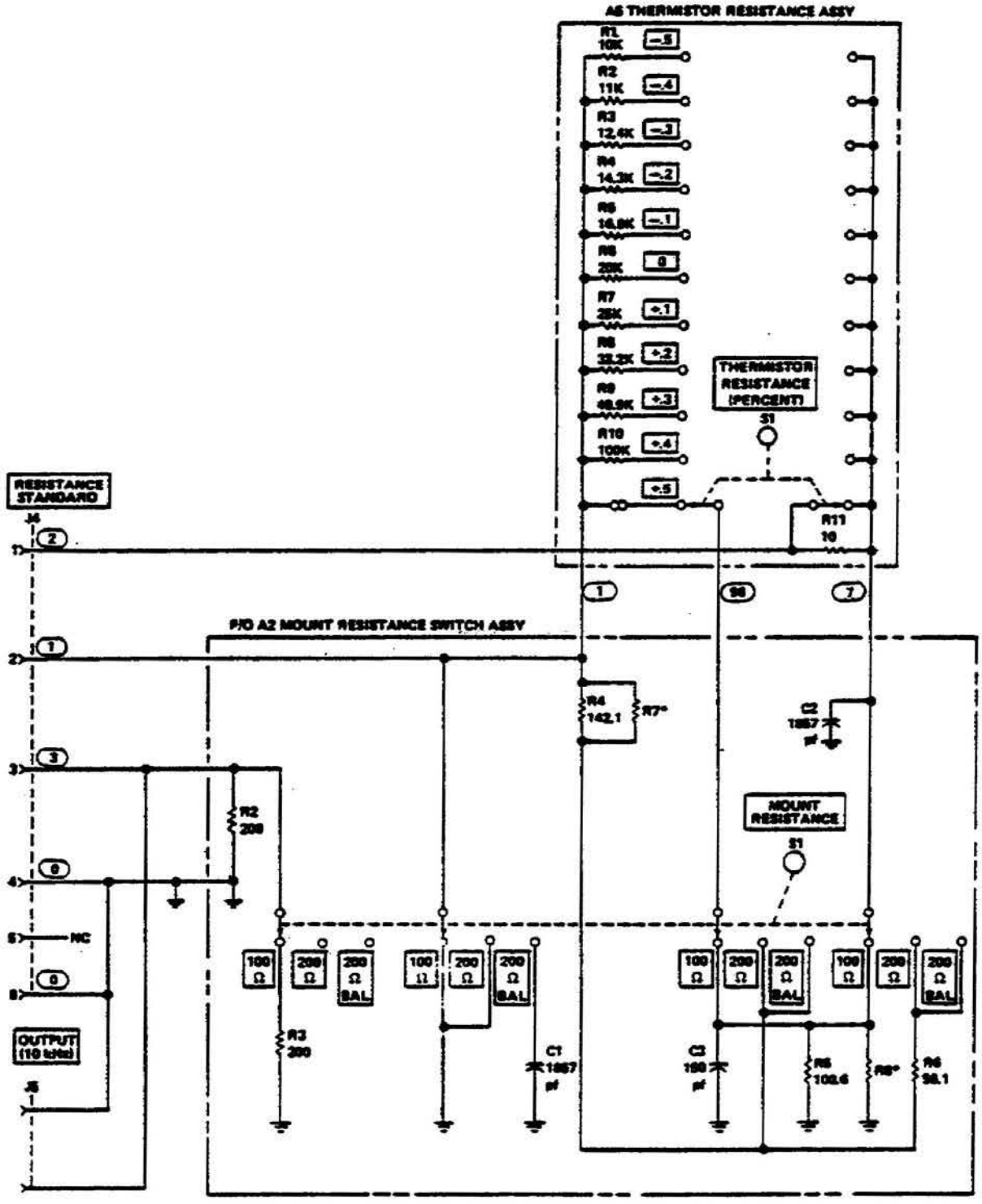


Figure 7. Thermistor resistance function.

state, respectively. On this basis, the power meter can be used to indicate the presence of the 10 kHz audio bias.

(3) With the 431C Power Meter RANGE switch set to NULL, a stable meter indication greater than zero indicates a 10 kHz oscillation and a meter reading of zero indicates no oscillation. The operating resistance of the detection thermistor element is somewhere between the percentage deviations indicated by the two switch settings that correspond to a no-oscillation and an oscillation state. The presence of an audio bias signal in the power meter can also be determined at the calibrator OUTPUT (10 kHz) BNC jack. This jack connects to the audio bias lead at the thermistor mount end of the thermistor mount cable.

7. POWER METER CALIBRATOR MODEL 8477A FOR THE MODEL 432A POWER METER
THE MODEL 8477A POWER METER CALIBRATOR IS USED TO CALIBRATE IT.

a. Description. The 8477A Calibrator is a specialized instrument designed to verify full-scale calibration of the model 432 Power Meter. Essentially a precision DC voltage source, the calibrator connects to the power meter's bridge circuits to simulate the effect of power dissipation in a thermistor mount.

b. Specifications.

(1) Calibration Function: Output voltages corresponding to meter reading of: 0.01, 0.03, 0.1, 0.3, 1, 2, 3, and 10 mW.

(2) Calibration Uncertainty: ±0.5% on 0.01 mW range and ±0.2% on 0.1 to 10 mW ranges.

c. Operation, function and purpose are similar to the model 8402B Power Meter Calibrator.

AIPD SUBCOURSE NUMBER MM0474, POWER MEASUREMENTS

EXERCISES FOR LESSON 3

1. What is the purpose of the 8402B calibrator?

   a. Calibrate power meters
   b. Calibrate thermistors
   c. Calibrate attenuators

2. Which statement best describes the Model 8402B calibrator?

   a. A precision decade attenuator
   b. An accurate source of AC power
   c. An accurate source of DC power

3. How is the internal thermistor mount resistance error determined, using the 8402B calibrator?

   a. By using the mount resistance switch setting
   b. By calibrator function switch
   c. By calibrator range switch

4. Which mode of operation is the fixed internal reference voltage used in?

   a. Substitute
   b. Calibration
   c. AC

5. What control provides the voltage required for the substitution mode of operation?

   a. Range
   b. Thermistor resistance
   c. Current control

6. What is the purpose of the differential amplifier (Q2, Q3) in the power supply of the 8402B?

   a. Provides reference for the +9V supply
   b. Provides reference for the -30V supply
   c. Compares the regulated output voltage to the Zener reference

7. What control on the Model 8402B permits a calibrator to check power tracking accuracy?

   a. Range
   b. Function
   c. Current control

8. Voltage present at the rear panel DIFFERENTIAL VOLTMETER jack is

   a. directly proportional to the substituted current.
   b. indirectly proportional to the substituted current.
   c. 1 Volt per 1 mW of power.

9. What will the load on the output be if a 10 megohm differential voltmeter is connected to the DIFFERENTIAL VOLTMETER jack?

   a. 10 megohms on all ranges
   b. 10 megohms on 1 to 10 mW ranges 100 megohms or greater on lower ranges
   c. No load if differential voltmeter is at null

10. Which switch on the 8402B calibrator provides a method of determining oscillator non-oscillation states of the 431C Power Meter?

   a. Thermistor resistance
   b. Function
   c. Mount resistance

11. What effect would A1VR2, in the precision current generator, have on the operation of the calibrator, if it is defective?

   a. No variable reference voltage
   b. No fixed reference voltage
   c. Inoperative substitute mode

12. What type output is generated from the Darlington-combination transistors A1Q6 and A1Q7 in the differential amplifier circuit?

   a. High voltage gain
   b. Low current gain
   c. High current gain

13. In the power supply circuit what effect will diode A1CR6, if open, have on the circuit?

   a. No reference -30 volts
   b, A1Q2 will saturate
   c. A1Q2 will cutoff resulting in -15 volt reference

14. With the 431C power meter range switch set the null, a stable meter indication greater than zero represents

   a. no oscillation.
   b. 10 kHz oscillation.
   c. 1 kHz oscillation.

15. What circuit in the 8402B is used to check out the 431C RP detection bridge?

    a. Thermistor resistance function
    b. The precision DC generator
    c. Differential amplifier

LESSON 4. POWER MEASUREMENT EQUIPMENT PART III

AIPD Subcourse MM0474.....Power Measurements

Lesson Objective.....After studying this lesson, you should be able to describe the purpose, characteristics and operation of the power standards set and the NBS power bridge. You should also be able to answer all exercise question without error.

Credit Hours.....Three

TEXT

1. INTRODUCTION.

At the Army Calibration Laboratory a requirement exists to certify thermistor mounts used in the Army Calibration System. To perform the power measurements at an accuracy sufficient to certify thermistor mounts the Army Calibration System uses an NBS Type II Power Measurement System.

2. DESCRIPTION.

a. The NBS Type II Power Measurement System, Figure 1, consists of two units: a self-balancing bolometer bridge, and a reference voltage generator. The bridge is a self-continued unit, but the reference generator draws its power from the bridge and can only be used with it or some other external power source.

b. The bridge is designed to measure microwave or high-frequency power in conjunction with an external bolometer mount (either a thermistor or a barretter) and some means of accurate voltage measurement. The reference voltage generator may be used for this purpose, although this does not generally result in the best accuracy for RF power levels less than about 80% of the normal DC bias power. Use of the reference voltage generator as a stable voltage source in conjunction with an external voltmeter produces the most accurate measurements. This technique is particularly important at low power levels, i.e., less than 10 milliwatts.

c. The reference generator is also designed to be used as a precision power stabilizer. It has two output connectors; one with a limited

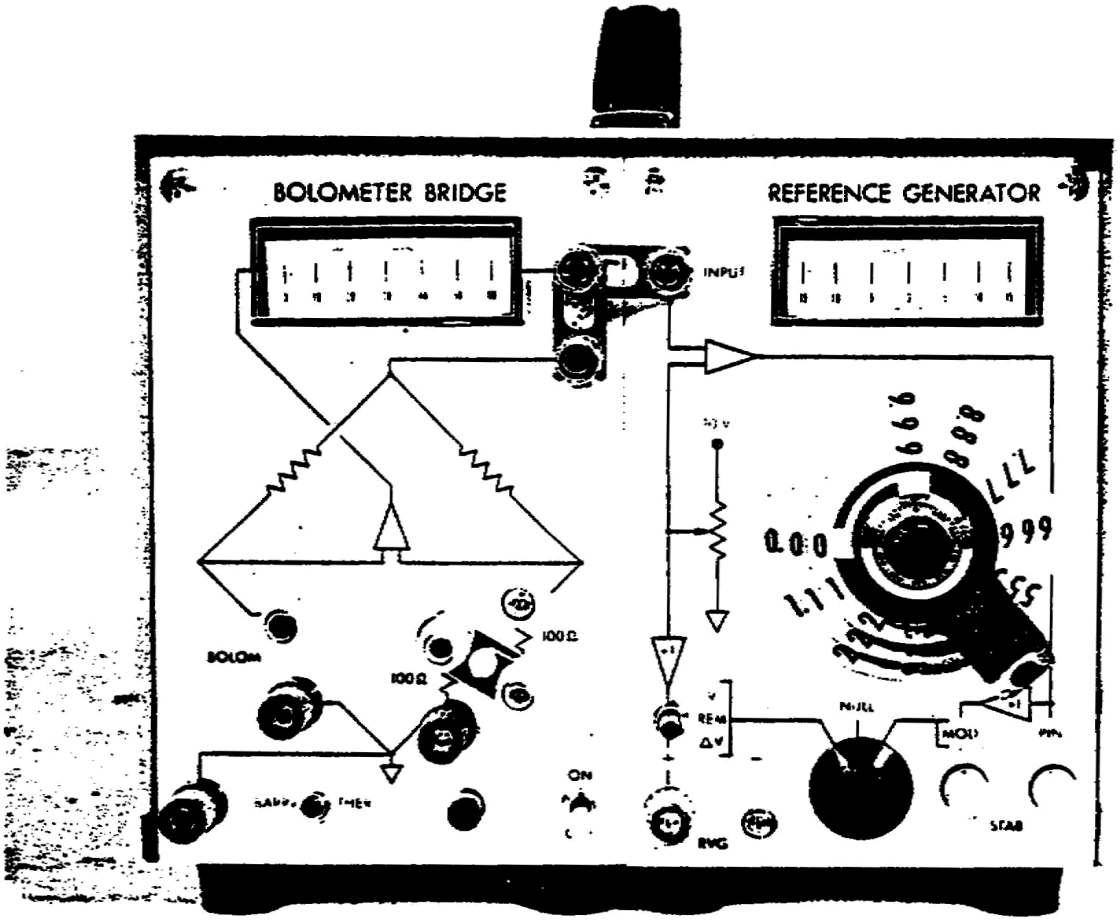


Figure 1. NBS Type II Power Measurement System.

power output capability to drive a Positive, Intransic, Negative (PIN) diode modulator, the other with a 300 mA maximum to drive a ferrite modulator.

d. Finally, the reference generator can be used as a 0-10 volt DC source. Output impedance is less than 20 milliohms; available output current depends upon the voltage setting. This output is short circuit proof, as are all other outputs available at the front panel or either the bridge or the reference generator.

e. The self-balancing bridge and the reference generator supplied as a unit have the same serial numbers. These may be found engraved upon the back panels. In addition, this number is engraved on each of the printed circuit boards used in the instruments.

f. Specification for the NBS Type II Bridge are found in Table 1A and 1B.

3. LOCATION AND FUNCTIONS.

a. The NBS Type II Power Measuring System is a standards laboratory quality instrument used to measure accurately high-frequency or microwave power in terms of substituted DC power. The instrument is not direct reading; the power must be calculated, generally using data obtained from an external precision voltmeter, but usually at reduced accuracy. The system is intended for use with non-temperature compensated bolometer mounts. These may have either a coaxial or waveguide input and contain a thermistor or a barretter as the bolometer element. The frequency and power range covered depends upon the bolometer mount used. In general the power level will not exceed 10 milliwatts. The unit may also be used as a precision power stabilizer. The following paragraphs contain the information necessary to operate the unit.

b. Rear Panel Controls: (Figure 2).

(1) THROUGH (3)

Q407, Q715, Q714. These are the reference designations of the transistors fastened to the other side of the panel. The rear panel is used as a heat sink for these semiconductors.

(4) CONNECTING CABLE. A 20 conductor cable and connectors supplying power and other necessary connections to the reference generator unit from the bridge unit. The connectors are removed by turning the knurled actuating screw in the center of the connector until the connector is free.

(5), (6)

Q111 +15 V, Q111 -15 V. These are the locations of the two identical pass elements for the two P100 power supply boards.

(7) LINE FUSE. This is a 1/4 amp slow-blow fuse.

(8) POWER CORD INPUT. The line cord supplied with the instrument should be used.

(9) CIRCUIT COMMON. This terminal is connected to the front panel terminal 4. The bridge and reference generator circuits may be disconnected from the power line ground by removing the link connecting this point with terminal 10.

TABLE 1A. SELF–BALANCING BRIDGE SPECIFICATIONS

POWER RANGE: Depends on external bolometer mount used.

Bolometer Mount Resistance	50 Ω	100 Ω	200 Ω
Bias Power at 60 mA Bridge Current (front panel meter maximum.)	45 mW	90 mW	180 mW
Maximum Bias Power	222 mW	250 mW	222 mW
Bridge Current at Max. Bias Power (Front panel meter shorted.)	133 mA	100 mA	67 mA

ACCURACY: The table below lists the error in a substituted dc power measurement of 10 mW rf, for two typical thermistor mounts. No term is included for the bolometer lead resistance, since this error is measurable and correctable.

Bolometer Mount	100 Ω Thermistor (Υ = −11,750 Ω/W)	200 Ω Thermistor (Υ = −12,300 Ω/W)
Bridge Arms Resistor Errors, Total	±0.0050%	±0.0054%
Bridge Electronics Errors, Total	±0.0008%	±0.0007%
Total Bridge Error	±0.0058%	±0.0061%
External Voltmeter Error	±0.0134%	±0.0108%
Total Error	±0.0192%	±0.0169%

The external voltmeter specifications are:

Range	% of Reading Error	% of Full Scale Error
1V	±0.007%	±0.002%
10V	±0.004%	±0.001%

NOISE: Less than 0.05 μW.

RESISTANCE OF BRIDGE ARMS: Known to ±0.005%, Y and Z differ by less than 0.002%.

MAXIMUM BRIDGE CURRENT: Up to 60 mA metered, up to 150 mA maximum.

POWER SUPPLIES: ±15 volts. Current limit at 500 mA ± 10%.

POWER: 105–130 volts AC, 50–60 Hz.

Table 1A. Specifications.

OUTPUT VOLTAGE: 0-10 volts

ACCURACY: ±15 ppm of reading immediately after calibration.

OUTPUT CURRENT: Depends on the voltage setting according to the equation $I_{out} = (10.4 - E_{out})/10$ amperes. Short circuit protected by ±15 V bridge power supply current limiting.

OUTPUT IMPEDANCE: 20 milliohms at front panel terminal.

DIVIDER: 6 place, 1 ppm resolution.

STABILITY: At constant temperature after 30 minute warmup.

1 Hr: 5 ppm of setting plus 1 μV.
24 Hr: 15 ppm of setting plus 2 μV.
30 Day: 100 ppm of setting plus 10 μV.

TEMPERATURE COEFFICIENT: (10 ppm + 1 μV) per °C.

VOLTMETER

RANGE: 10 volts.

ACCURACY, STABILITY, AND TEMPERATURE COEFFICIENT: Same as reference voltage generator.

INPUT IMPEDANCE: Greater than 10^9 ohms at null, decreasing to 200 ohms minimum at 1 volt or more off null. Voltmeter input will appear as a source or a sink as setting is above or below unknown voltage

POWER STABILIZER

OUTPUT CURRENT:

PIN: 5 mA maximum.
MOD: 300 mA maximum.

STABILIZATION FACTOR: $\Delta P_{rf\ out}/\Delta P_{rf\ in}$

At 0.1 mW through 10 mW rf in a 200 ohm thermistor leveling detector: $< 10^{-6}$ typical.

Table 1B. Reference Voltage Generator

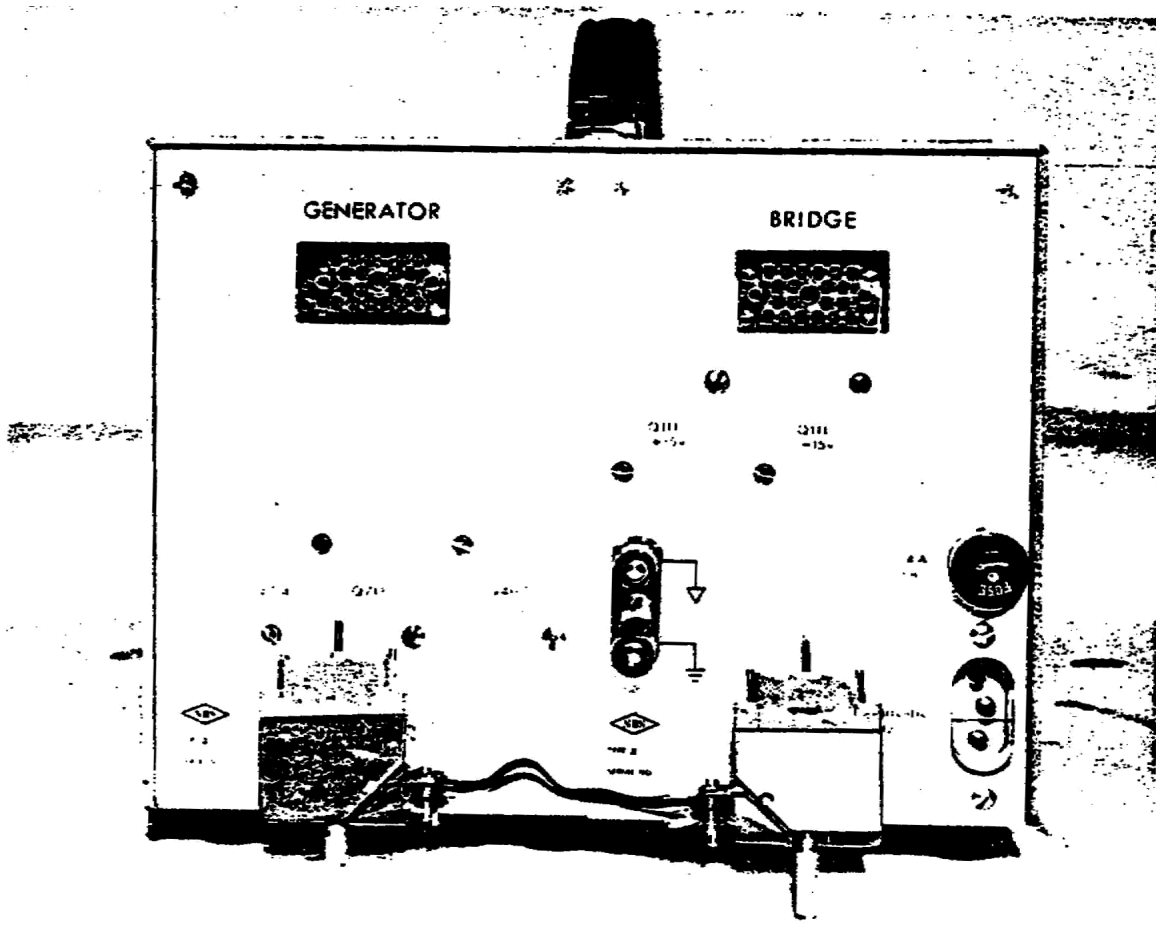


Figure 2. Back panel designations and connectors.

(10) CHASSIS COMMON. This terminal is connected to the chassis and to the power line third wire ground.

c. Front Panel Controls, Connectors, and Indicators.

(1) POWER. Instrument power ON/OFF Switch (S1).

(2) PILOT LIGHT. Indicates when instrument power switch is ON.

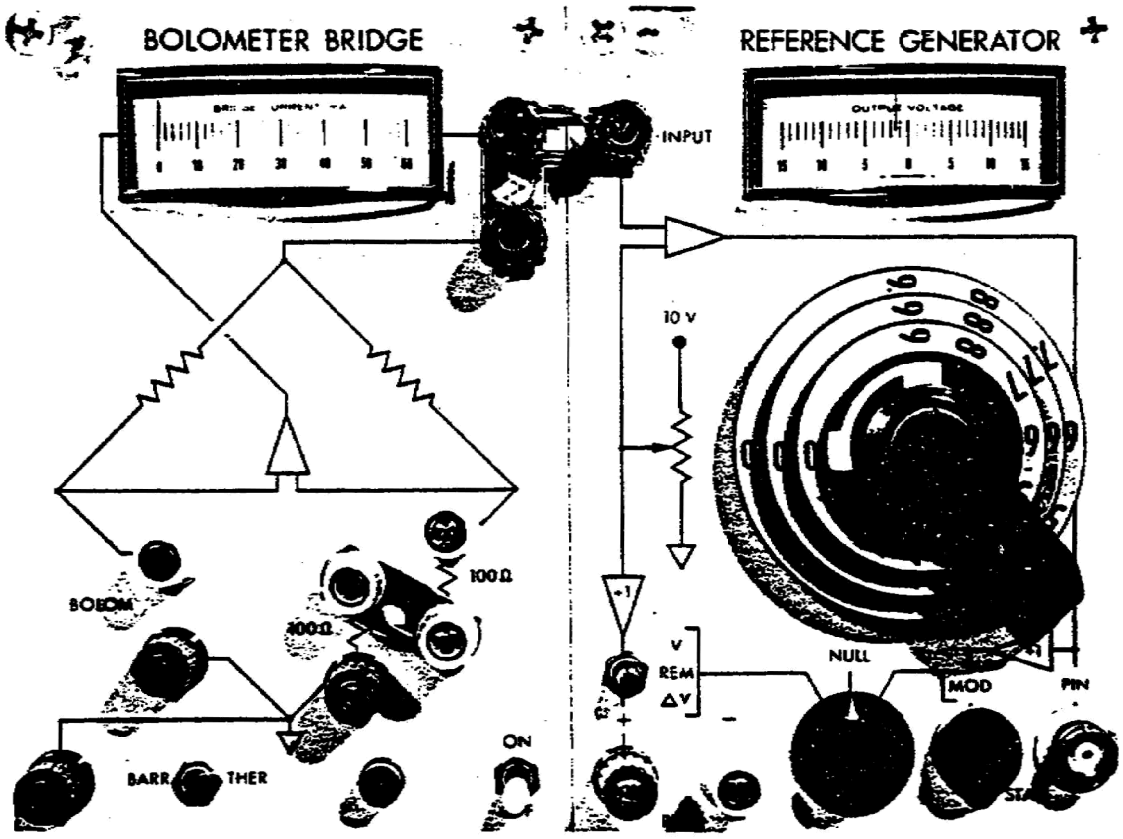


Figure 3. Front panel controls, connectors, and indicators.

(3) BARRETTER/THERMISTOR SWITCH. Selects amplifier feedback polarity and response shaping networks in both bridge and generator for either a positive or negative temperature coefficient bolometer elements (S601).

(4) COMMON REFERENCE TERMINAL. Common ground return point for all bridge and reference generator circuits.

(5) BOLOMETER MOUNT NEGATIVE TERMINAL.

(6) BOLOMETER MOUNT POSITIVE TERMINAL. The connecting leads to the bolometer mount should be as short as possible. For the most accurate measurement lead resistance should be measured and corrected for.

(7) THROUGH (10).

MOUNT RESISTANCE. The position of the removable links on these terminals determines the operating resistance of the bolometer

mount. The proper position may be determined by noting the connections to the 100 ohm resistors as indicated by the front panel or by referring to Figure 4, which show the link positions for various operating resistances. An external resistance standard may be connected if the desired operating resistance cannot be achieved with the internal resistors.

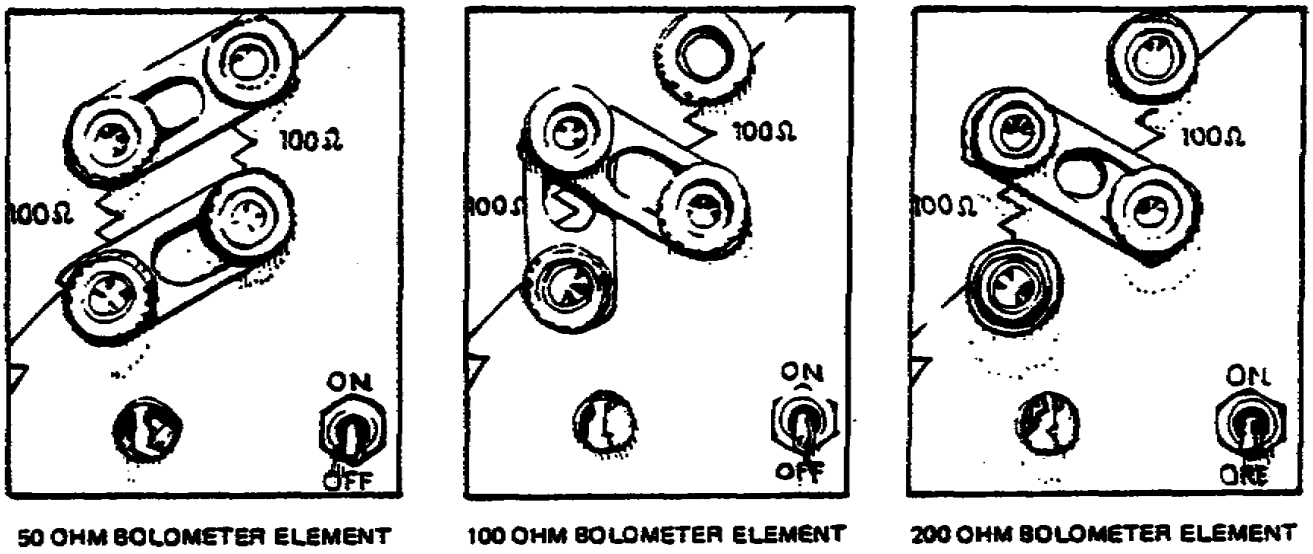


Figure 4. Front panel link positions.

(11) BRIDGE CURRENT METER. Indicates the total bridge current ±3%. Not used for power measurement.

(12), (13)

CURRENT SAMPLING TERMINALS. If it is desired to measure accurately the bridge current, an external ammeter may be inserted at this point. If it takes the form of a current sampling resistor, the total voltage between terminals 13 and 4 should not exceed LO volts to ensure proper bridge balancing.

(14) REFERENCE GENERATOR INPUT TERMINAL. This terminal is normally connected by a link to the top of the bolometer bridge, terminal 13, as indicated in the figure. When the reference generator is used as a voltmeter in the NULL mode, it is the positive input. The negative input is accomplished through the rear cable.

(15) OUTPUT VOLTAGE METER. In the reference voltage generator mode, (RVG), this meter displays the voltage to which the decade divider dials are set. In the voltmeter (NULL) mode, the meter indicates the output of the null detector amplifier. In the stabilizer (STAB) mode, the meter monitors the output voltage of the leveling amplifier and may be used to help determine when the stabilizer is operational, particularly when used with PIN diode modulators.

(16) DECADE DIVIDER. This 6-place divider is direct reading in volts. The decimal point follows the number on the largest dial. To read the decade divider refer to Figure 5.

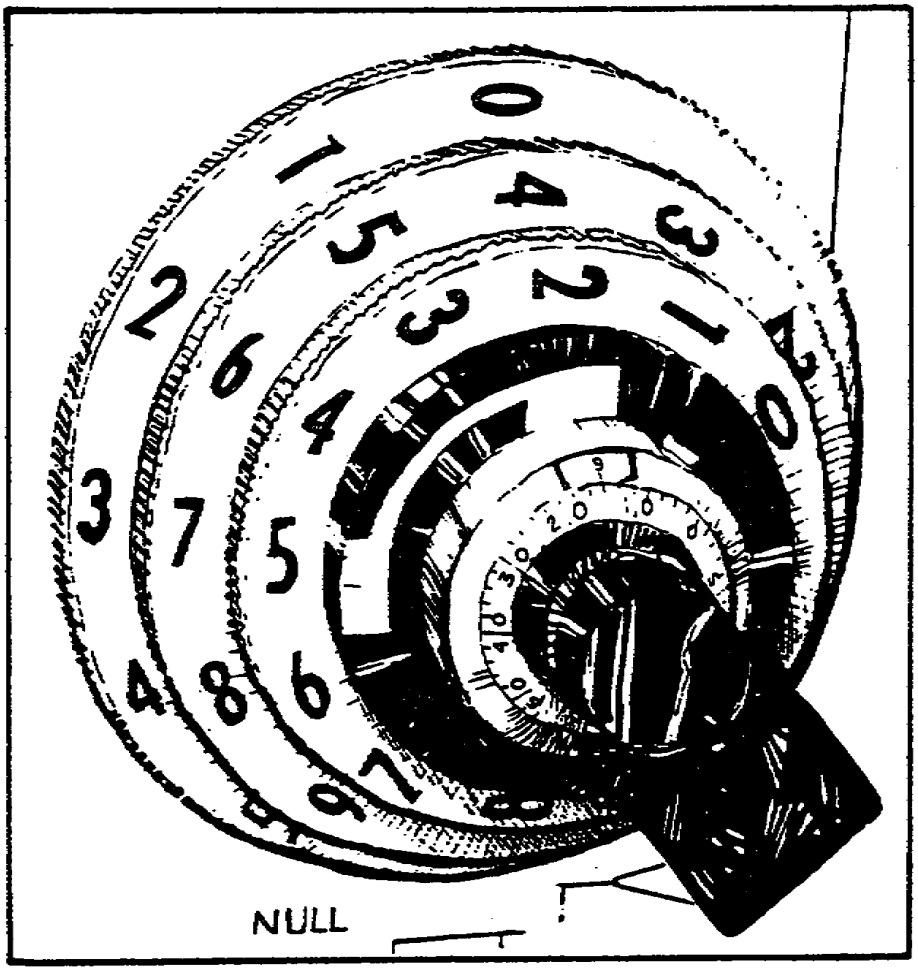


Figure 5. Reading of divider dial. Dial is set to 3.75914 volts.

(17) V-REM-ΔV SWITCH. This switch controls the voltage appearing at binding posts 21 and 22 located just below the switch. In the V position voltage across the bridge (from terminal 14 to terminal 4) appears at terminals 22 and 21. This occurs independently of the setting of the RVG-NULL-STAB switch. In the ΔV position the positive output of the reference voltage generator is connected to terminal 22 and the top of the bridge to terminal 21. Thus the difference between them may be read on a "floating" external voltmeter. The RVG-NULL-STAB switch must be in the RVG position for a meaningful output. In addition the output of the reference voltage generator can be obtained between terminal 22 and 4. The center REM position is for a possible future

circuit addition and is not operational on these units. The RVG terminals are floating when the switch is in the REM position.

(18) STABILIZER MODULATOR OUTPUT TERMINAL. This terminal is a high current output of the leveling amplifier. It will supply up to 300 mA to meet the requirements of a ferrite modulator. The shell of the connector is tied to terminal 4 and is insulated from the instrument chassis.

(19) STABILIZE PIN MODULATOR OUTPUT TERMINAL. This terminal is a direct output of the leveling amplifier. The maximum output current of the amplifier is approximately 5 mA, which provides protection for the PIN diodes. The shell of the connector is tied to terminal 4 and is insulated from the instrument chassis.

(20) REFERENCE GENERATOR FUNCTION SWITCH. Selects one of three different reference generator modes of operation. To the left of center (RVG) provides the reference voltage output, center provides the voltmeter (NULL) function, and right of center provides the stabilizer (STAB) function.

(21) and (22)

RVG OUTPUT TERMINALS. The various outputs associated with the primary function of the reference voltage generator, i.e., precision power measurement, appear at these terminals. A complete description of the voltages available at these terminals is included in the description of the functions of switch 17.

4. PRELIMINARY OPERATING INSTRUCTIONS.

a. Before connecting the bolometer determine its operating resistance by the label or stamping on the housing and whether it is a barretter or thermistor. The following steps describe the initial operations.

(1) With instrument turned off, set BARR-THER switch according to the type of bolometer mount being used. If this switch is not set properly it is possible to destroy a bolometer element, particularly a barretter. It is advisable to turn the instrument off before changing the switch setting.

(2) Attach the lower links as appropriate for the mount operating resistance.

(3) Make certain upper links are attached as shown and described in Figure 4.

(4) The rear grounding link should be in place unless it is necessary to float the instrument above ground.

(5) The bolometer mount may now be attached to the bridge and the instrument turned on.

b. Precision Power Measurement (Figure 6). This measurement requires the use of an external voltmeter. The accuracy of this voltmeter should be as accurate as possible, since its error contributes directly to the overall measurement error. The voltmeter should be connected to binding posts 21 and 22 located on the lower part of the reference generator.

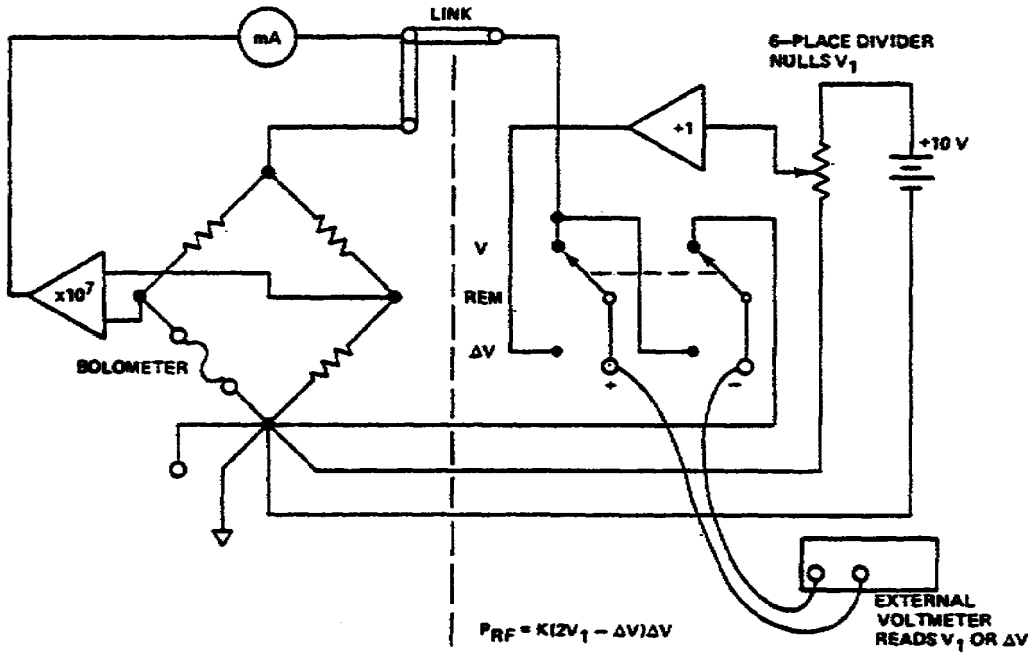


Figure 6. Precision power measurement system.

c. Measurement Procedure.

(1) After the instructions of para 4a have been followed, turn on the bridge and allow a 15 minute warm up period.

(2) The bolometer mount should be attached to the RF power source, but with the RF power off.

(3) Place the reference generator function switch in the NULL position and the V-REM-ΔV switch at V. Adjust the divider dials to zero.

(4) Turn the main divider dial clockwise until the meter deflects to the right, then turn the dial back one division. Repeat this operation with each successive dial until the final null is obtained with the ten-turn dial. Note that since the null detector is an integrator it is not necessary that the meter pointer be on zero, but only that pointer movement be stopped. Some drift in the null will probably be observed. This is due to thermal drift of the bolometer element.

(5) Once the null has been obtained place the reference generator function switch in the RVG position (full counterclockwise).

(6) Record the voltmeter reading, which will be designated V_1. (Note that this voltage is nominally the same as appears on the divider dials.)

(7) Turn on the RF power and move the V-REM-ΔV switch to ΔV.

(8) Record the voltmeter reading, which is ΔV.

(9) Calculate the power using the expression:

$$P = K(2V_1 - \Delta V)\ \Delta V$$

The proper value of K is obtained from Table 2.

MOUNT RESISTANCE	K
50 Ω	$\frac{1000}{450} = 2.222\ldots$
100 Ω	$\frac{1000}{400} = 2.500\ldots$
200 Ω	$\frac{1000}{450} = 2.222\ldots$

Table 2. Values of K for Various Bolometer Mount Operating Resistances (Gives Power in Milliwatts)

d. Self-Contained Power Measurement. This procedure is not recommended where the highest accuracy is desired. It has the advantage of being completely self-contained, i.e., no other external voltage measuring equipment is needed.

e. Measurement Procedure.

(1) After the initial steps of para. 4a have been followed, turn the instrument on.

(2) The bolometer mount should be attached to the RF source with the RF turned off.

(3) Place the reference generator function switch in the NULL position and the V-REM-ΔV switch at V. Adjust the divider dials to read zero.

(4) Turn the main divider dial clockwise until the meter deflects to the right, then turn the dial back one division. Repeat this operation with each successive dial until the final null is obtained with the ten-turn dial. Note that since the null detector is an integrator it is not necessary that the meter pointer be on zero, but only that pointer movement be stopped. Again, some drift in the null will probably be observed. This is due to thermal drift of the bolometer element.

(5) Record the divider dial reading as V_1.

(6) Turn the RF power on and repeat steps (3) and (4).

(7) Record the second divider dial reading as V_2.

(8) Calculate the power using the expression:

$$P = K(V_1^2 - V_2^2)$$

Again the proper value of K is obtained from Table 2.

5. PRECISION POWER STABILIZER (FIGURE 7).

a. The reference generator is also designed to be used as a precision power stabilizer. It requires use of an external modulator which may be either a PIN diode or ferrite type. The PIN output has a limited current capability to protect delicate PIN diodes; the MOD output is capable of delivering up to 300 mA to the modulator. Both outputs swing negative with an increase in RF power. In addition, either output may be used to control ground-referenced grid-leveled sources. In this application, it may be necessary to attenuate the stabilizer output if the signal source contains its own leveling amplifier, because such amplifiers usually introduce enough phase shift to cause oscillations. They are generally much less stable in terms of long-term drift than the amplifier contained in the reference generator, so that best performance will be obtained using the reference generator in the stabilizer mode to provide all of the necessary gain in the stabilizing loop. When used as a stabilizer, the instrument provides the equivalent of an extremely high resolution attenuator, because of the 1 ppm resolution of the 6-place divider.

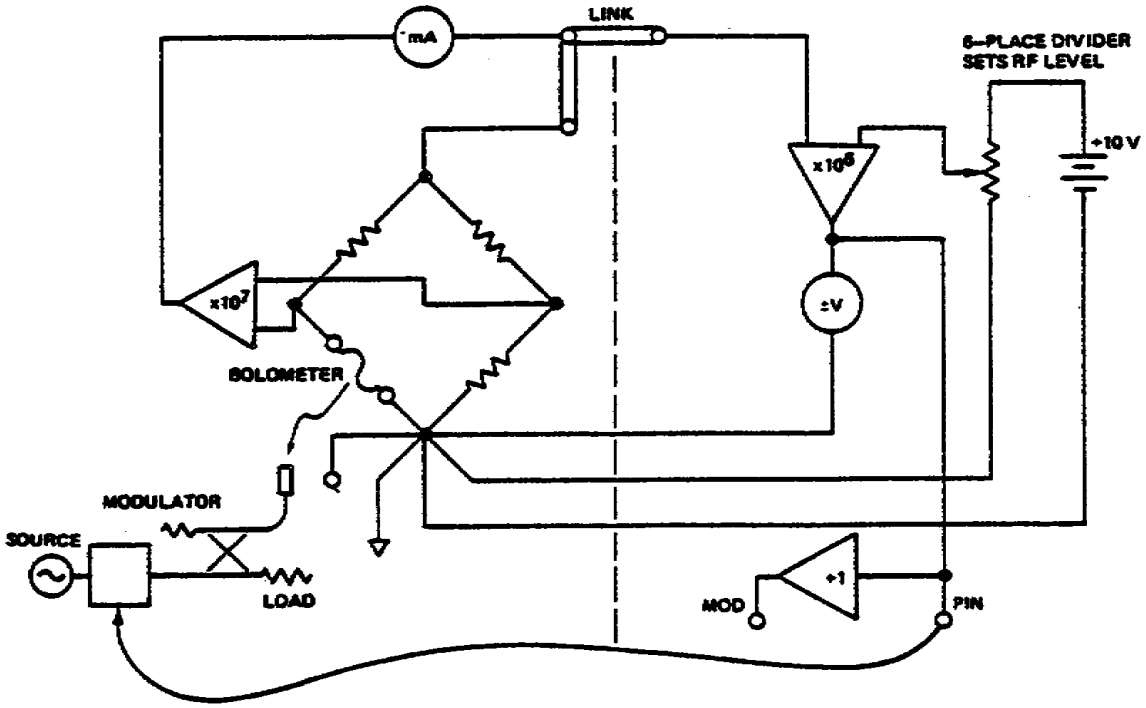


Figure 7. Precision power stabilizer.

b. Operating Procedure-Power Stabilizer.

(1) The initial steps of para. 4a should be followed first. In addition, place the reference generator function switch in the STAB position and connect the modulator to the appropriate front panel terminal.

(2) With the bridge on, and the RF off, note the bridge voltage and set the reference generator divider dials to that voltage or slightly higher. This may be done with an external voltmeter or by using the reference generator as a voltmeter as outlined in para. 4e. If the latter technique has been employed, place the generator function switch back in the STAB position after determining the voltage. Setting the stabilizer operating point in this manner, before turning the RF power on, insures that the modulator will be set to nearly its maximum attenuation. This prevents possible excessive power from reaching the leveling bolometer mount or the load.

(3) Turn on the RF power and reduce the voltage setting of the divider dials to the desired operating point. A corresponding reduction in bridge current should be noted. The maximum RF power available to the leveling mount should be such that setting the divider dials to zero does not result in a reduction of bridge current to zero. In other words, when the leveling modulator is set to its minimum attenuation, the RF power arriving at the leveling mount should not exceed its DC

bias power. If this condition is not met, there is a chance of oscillation occurring in the leveling loop or of excessive RF power damaging the leveling mount. In general, the operating point of the stabilizer should be chosen so that somewhere between 10% and 90% of the DC bias power is replaced by RF. This may be adjusted by changing the sampling directional coupling ratio, or by placing a level-set attenuator in the sampling arm.

(4) If difficulty is experienced in using a ferrite modulator it may be necessary to reverse the polarity of the connection to the modulator. It is desirable to use a modulator which has its attenuation minimum at zero bias current, independent of the RF frequency. If this is not the case, it may be necessary to use a very small external bias magnet on the modulator.

(5) If a PIN diode modulator is being used, one may tell by the indication on the output voltage meter if the stabilizing loop is operational. Usually it will read a few tenths of a volt negative.

(6) For either a PIN diode or ferrite modulator, a video detector and oscilloscope may be used to determine if the leveling is satisfactory. The detector may be attached to the side-arm of a directional coupler located on the load side of the modulator.

6. PRECISION 0-10 VOLT DC SOURCE (FIGURE 8).

a. The reference generator can be used as a precision 0-10 volt DC source. The output impedance is almost entirely the contact resistance of the V-REM-ΔV switch (S702). This is typically 10-20 milliohms. If a connection is made to the rear of the switch, an output impedance in the micro-ohm range can be achieved. The unit will furnish a current which depends upon the voltage setting, providing more current at lower voltages before errors due to loading occur. In particular, a current may be drawn which is not more than given by the equation

$$I_{out} = (10.4 - E_{out})/10 \text{ amperes.}$$

This output is short circuit proof. It is protected by the current limiting provided by the +15 V power supply in the bridge unit.

b. Operating Procedure - 10 Volt Source.

(1) Since the reference generator obtains its operating voltages from the bridge, both must be turned on. If it is desired to operate a bolometer mount, it can be connected to the bridge as described in para. 4a. If not, set the BARR-THER switch in the BARR position before turning the instrument on. When turned on, the bridge current will remain at zero with nothing connected to the bolometer terminals.

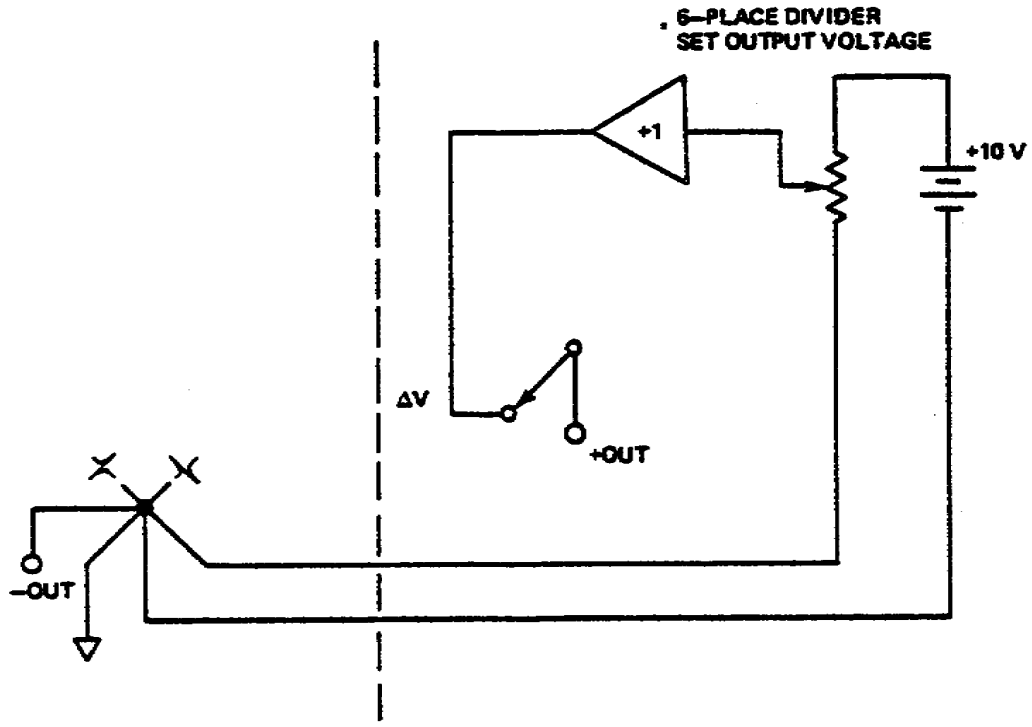


Figure 8. Precision 0-10 volt DC source.

(2) Place the V-REM-ΔV switch in the ΔV position.

(3) Set the divider dials to the desired output voltage, which will appear between terminal 22 (positive) and the bridge common terminal, 4.

7. PRINCIPLES OF OPERATION.

a. General. The power measurement system consists of two units: a self-balancing bolometer bridge and a reference voltage generator. The latter can also serve as a voltmeter or a power stabilizer. The self-balancing bridge is a DC substitution type. Improved performance and size reduction have resulted from redesign and the availability of improved components. The new instrument is completely solid state and makes use of integrated circuits.

b. Basic System.

(1) Figure 9 shows a block diagram of the basic measurement system. The self-balancing bridge unit appears to the left and the reference generator to the right of the dotted line. Not all of the front panel controls appear in the figure; however, two of the front panel links and the panel meters are shown. Operation of the bridge is

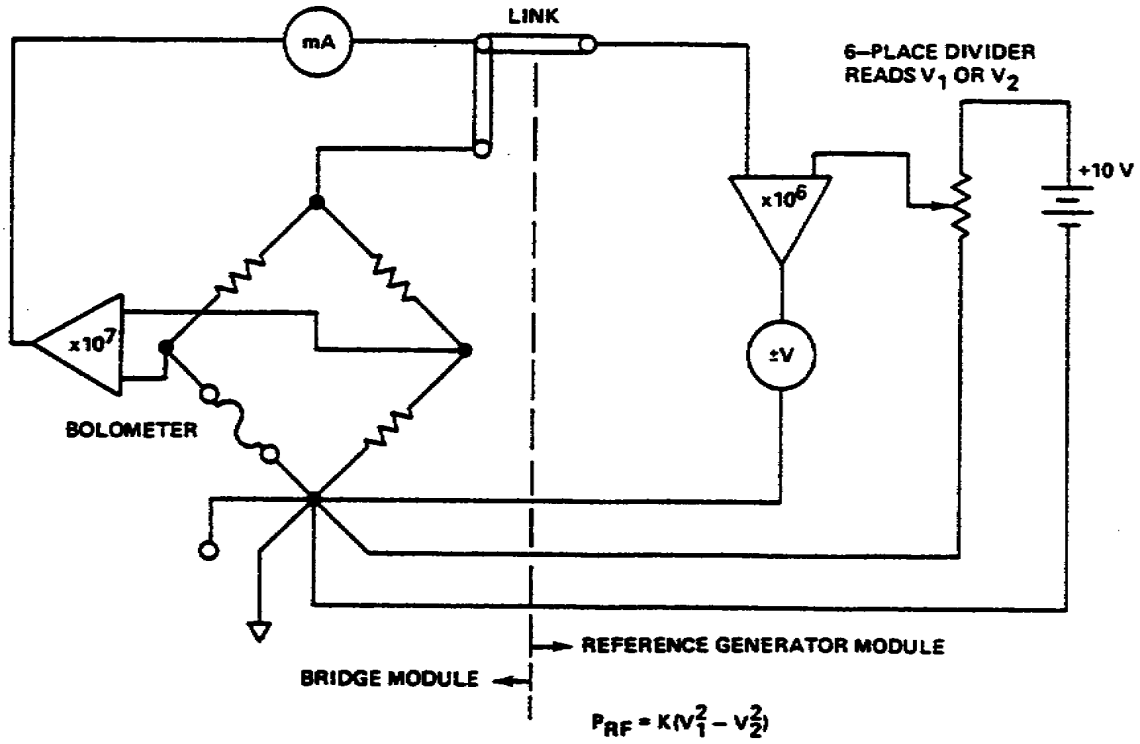


Figure 9. Basic measurement system.

straightforward. The operational amplifier marked X10^7 senses the bridge balance and adjusts the bridge current up or down to maintain a null at the amplifier input terminals. As RF power is applied to the bolometer its resistance will increase (if the element is a barretter). The bridge circuit detects this and reduces the bridge current to maintain the bolometer element resistance constant. This reduction in DC power is calculated and is ideally equal to the RF power dissipated in the bolometer element. (In practice it is not exactly equal to the RF power because of DC-RF substitution errors.)

(2) In Figure 9, the reference generator is connected as a voltmeter with the function switch in the NULL position. The amplifier marked X10^6 (G700 board) is acting as a null detector, indicating when the divider dials are set to the voltage appearing at the top of the bridge. This voltage .is measured first with the RF off (V_1) and then with the RF on (V_2). The RF power as a function of V_1 and V_2 is given by the expression at the bottom of the figure. The value of K depends upon the operating resistance of the bolometer element used. The value of K is given by:

$$K = \frac{1}{R_o(1 + R/R_o)^2}$$

where R_O is the element operating resistance, and R is the value of each of the two "top" arms of the bridge. In this bridge, R is equal to 100 ohms, so that the expression for K becomes:

$$K = \frac{1}{R_o(1 + 100/R_o)^2}$$

(3) The divider dials are direct reading to nominally ±0.01%, but using this method does not result in the most accurate power measurement. This is particularly true at low RF power levels where V_1 and V_2 are nearly equal in value. The dotted line in Figure 10 reveals this. Note that both curves in this figure are the result of using a voltmeter with the accuracy stated in Table 1 under ACCURACY.

c. Precision Power Meter.

(1) Figure 6 indicates that an external voltmeter is required for this procedure. This voltmeter should be the most accurate available. The following section on error analysis gives an expression for the error in the measurement due to the uncertainties in the voltmeter. The V-REM-ΔV switch is shown in the figure. The bridge circuit remains the same, but the reference generator operational amplifier has been connected as a unity gain follower. This is done by placing the function switch in the RVG position. The follower isolates the divider from leading errors.

(2) The basic power measurement equation may be rewritten giving the expression of Figure 6. Here V_1 is the DC bias bridge voltage, and ΔV is the change in the voltage when RF is applied to the bolometer mount. If the divider is set to the voltage V_1, then, when the RF is turned on, a voltmeter connected between the bridge and the divider output will indicate the change in voltage ΔV, directly. K is the same as given in Paragraph 7b.

(3) An examination of Figure 6 will show chat when the V-REM-ΔV switch is in the V position shown, the voltmeter can read V_1. When in the ΔV position, the external voltmeter may be used as a mill detector for setting the divider and then also for reading ΔV. (The REM position is for a possible future circuit addition and is not active in these units.)

(4) As Figure 10 shows, the error in making the DC substituted power measurement by this method is reduced substantially. The discontinuities in the curve are due to range changes in the external voltmeter.

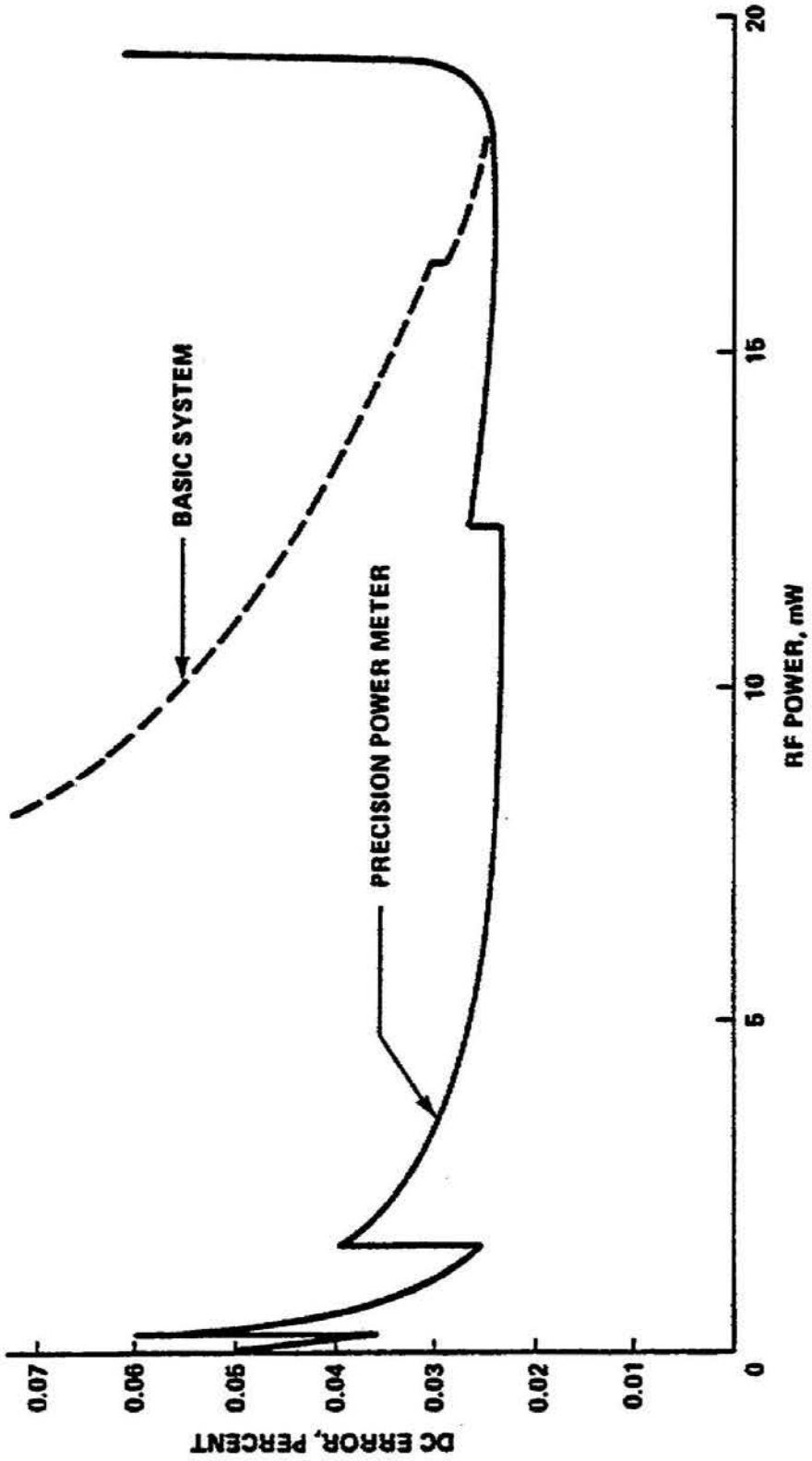


Figure 10. Worst case DC measurement errors.

Note that both curves in this figure are the result of using a voltmeter with the accuracy stated in Table 1 under ACCURACY.

d. Precision Power Stabilizer. Figure 7 shows the circuit arrangement. To obtain this, the generator function switch is placed in the STAB position. In operation, the reference generator amplifier compares the voltage at the top of the bridge with the reference voltage set by the 6-place divider and adjusts the modulator attenuation to keep them equal. The PIN modulator output connected directly to the operational amplifier is limited in the amount of current it can supply. This provides a measure of protection for the PIN diodes. The MOD output can provide a much higher current from an emitter follower.

e. 0-10 Volt Supply. In the circuit shown in Figure 8, the reference generator amplifier is again used as a unity gain follower. The function switch is placed in the RVG position and the V-REM-ΔV switch in the ΔV position. The output voltage appears between terminals 22 and 4. The maximums available output current is given under the reference generator specifications in Table 1.

f. Bridge Circuit Description.

(1) The operation amplifier marked $X10^7$ in Figure 9 is comprised primarily of Q609, Q614, and Q615 on the B600 board (refer to Figures 11 and 12). The error signal, due to bridge unbalance, appears at terminals E4 and E5 and is amplified by the differential pair Q609. The output from Q609 is buffered by Q614, with a voltage gain of approximately 1, into operational amplifier Q615. The output of Q615 is then returned to the base of Q601 which drives the top of the bridge through terminal E13.

(2) Transistors Q610, Q611, and Q612 form a constant current source for Q609. The negative 15 volt power supply voltage is used as a reference. Transistors Q608 and Q613 isolate Q609 from common mode voltage changes which appear at terminals E4 and E5 as the bridge current varies. The use of this circuit arrangement affords a common mode rejection ratio typically in excess of 126 dB, if Q608 and Q613 are matched. Matching is accomplished by measuring the change in the gate-source voltage at a constant source current of 30 microamps while the gate voltage is changed from 0 to 10 volts. Units which exhibit the same change in the gate source voltage to within 1% are selected as pairs.

(3) The output resistance of the differential input stage is 200,000 ohms at each output. This is buffered by Q614 to isolate the relatively high bias currents drawn by the inputs of Q615. Both Q609 and Q614 are integrated circuits which utilize a heated, temperature-controlled chip to maintain constant offset voltage and bias currents. The differential output from Q614 passes through polarity reversing switch S601B and S601C, two sections of the thermistor-barretter switch. Diode D605 disconnects Q615 from power amplifier Q601 if a turn-on

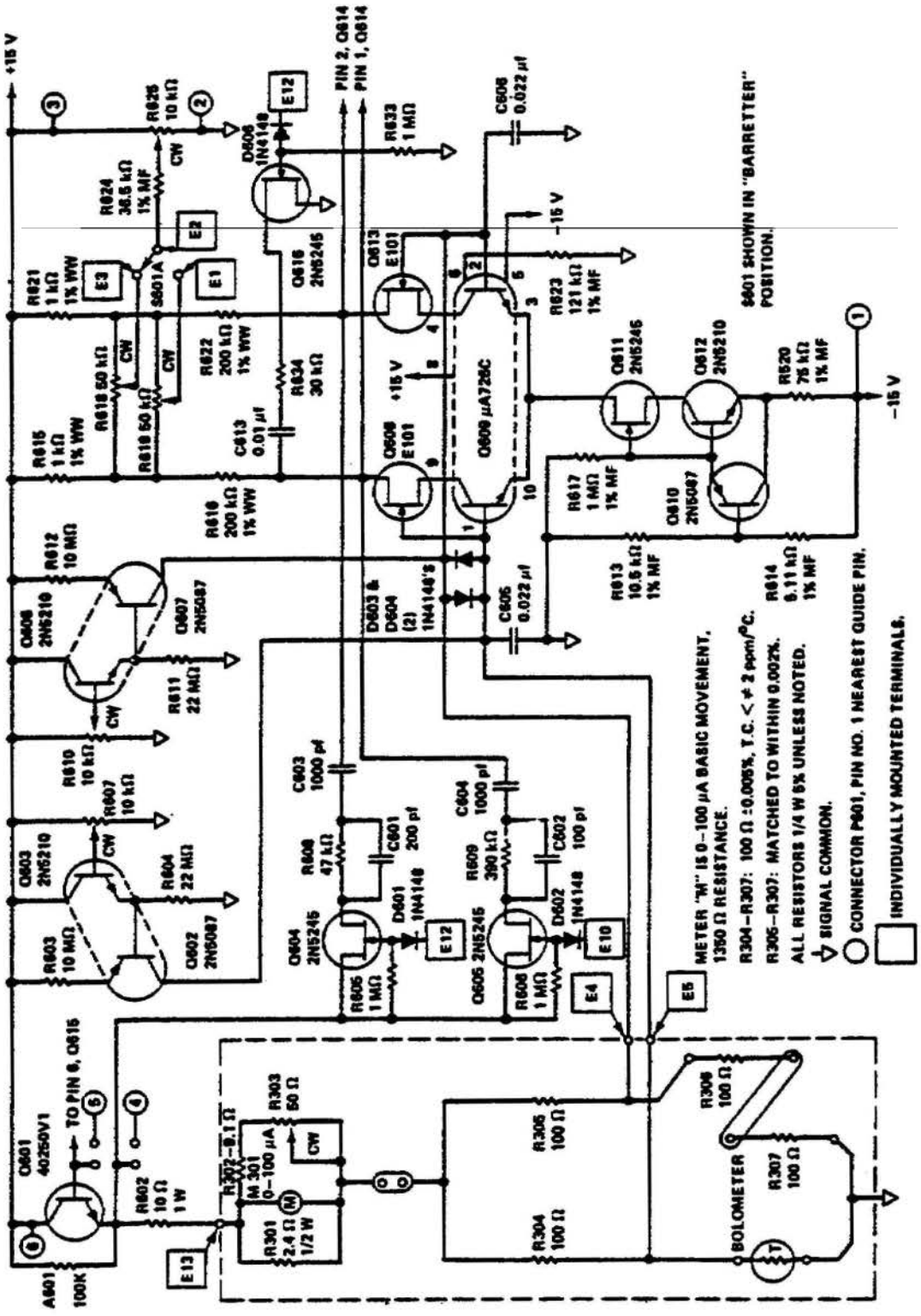


Figure 11. B600 bridge amplifier schematic part 1.

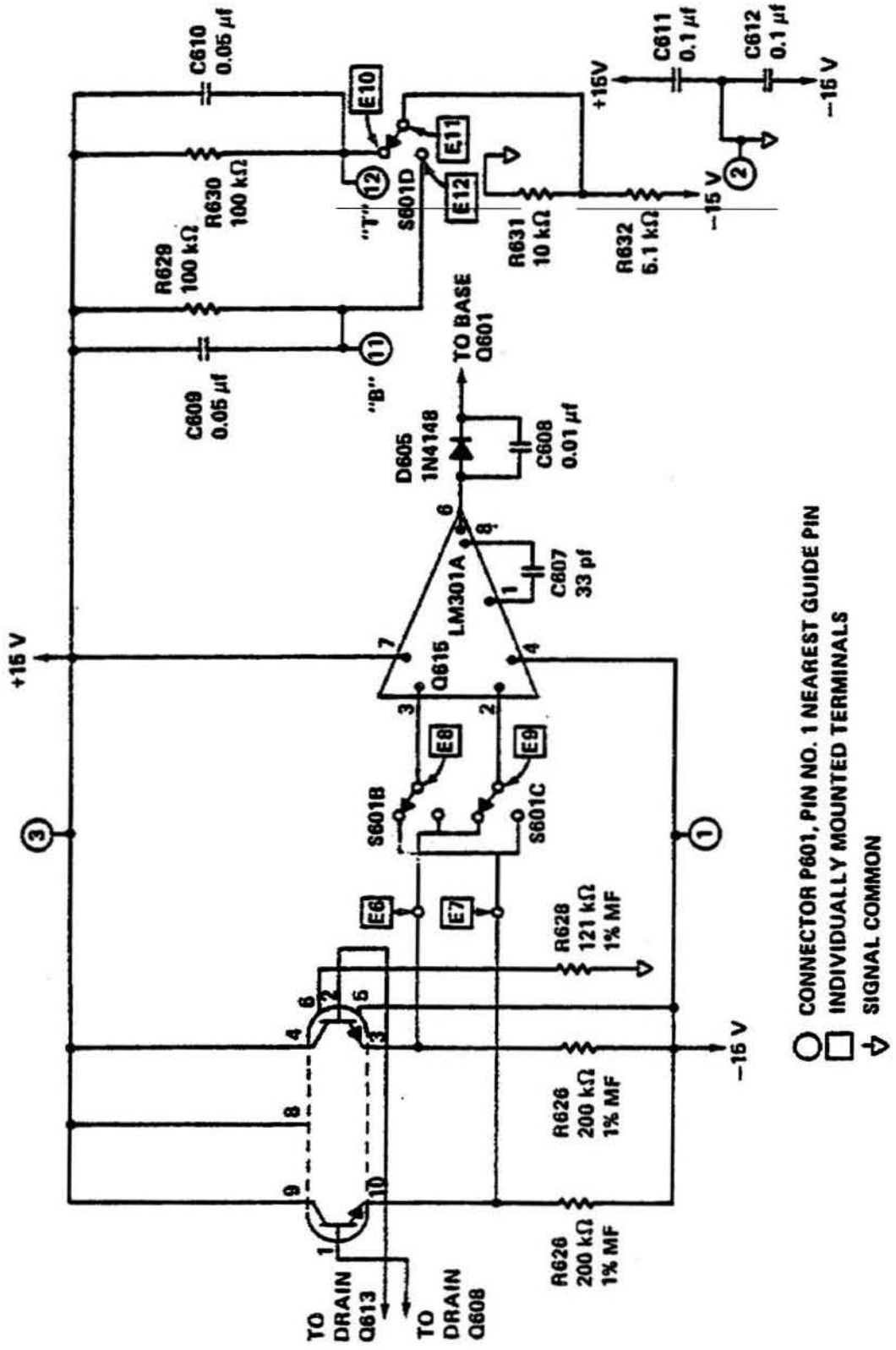


Figure 12. B600 bridge amplifier-schematic part 2.

transient should cause the output of Q615 to go negative. Power amplifier Q601 then drives the bridge through terminal E13 and bridge current meter M301.

(4) Solid state amplifiers using bipolar transistors in the input stage exhibit two types of non-ideal behavior which must be compensated for, if the best accuracy is required. The first of these is an equivalent voltage offset at the input terminals, E4 and E5, which is due to imperfect matching of the two halves of Q609. This offset is cancelled by unbalancing the collector circuits of Q609 with R625 and either R618 or R619, depending on whether the instrument is being used with a barretter or a thermistor. These two adjustments are made as described in para. 4 by nulling the voltage between terminals E4 and E5. These voltages are available at the front panel terminals.

(5) The second type of non-ideal behavior is the bias current required by the two halves of Q609. These currents must be drawn through R304 and R305 if not otherwise provided. To the extent that the bias currents flow through the bridge, they will produce an error in the substituted DC power measurement. Therefore, the currents drawn by Q609 at terminals 1 and 2 are individually compensated by constant current generators. One of these is composed of Q602 and Q603, and the other of Q606 and Q607, with the associated resistors. These two sources introduce currents into terminals 1 and 2, which are independent of the DC voltage between those terminals and signal common. The adjustment of these current sources is also described in para. 4 and consists of nulling the currents which pass through terminals E4 and E5.

(6) The self-balancing bridge is essentially a servo-mechanism and as such, the AC characteristics of the balancing amplifier are important. It is necessary to provide AC feedback loops within the amplifier to compensate the servo-mechanism for the characteristics of the load which it drives, in this case, the bridge itself, which includes the bolometer. Since the bolometer may be either a thermistor, which is relatively slow, or a barretter, which has a shorter time constant, the AC compensation networks must be changed according to the setting of the barretter-thermistor switch. These networks are associated with high impedance portions of the circuit, and in order to avoid the effects of variation of stray lead capacitances, the networks are located on the B600 board and are switched by field effect transistors controlled by the barretter-thermistor switch. There are three such networks on the B600 board. The two networks switched by Q604 and Q616 are in use in the barretter position. Alternately, the network switched by Q605 is used in the thermistor position.

g. Reference Generator Circuit Description.

(1) The reference generator has three basic modes of operation as outlined in para. 3. These are the NULL modes as used in the basic system, the reference generator or RVG mode and the stabilizer or STAB mode. These will be discussed in order.

(2) The heart of the reference voltage generator is another high gain differential-input operational amplifier similar to the one used in the bridge, it has a lower open loop gain, a higher common mode voltage limit, and larger output current capability (refer to Figure 13).

(3) The input stage for the amplifier is Q704. Transistors Q705, Q706, and Q707 furnish a constant emitter current to the two halves of Q704. Transistors Q703 and Q708 isolate the input stage from the large common mode voltages which must be accommodated in this application. Transistors Q703 and Q708 must be matched in accordance with the technique described in Paragraph 7f (2). In this case, however, the measurements are made at source currents of 150 microamps. The post-amplifier, Q713, is coupled directly to the drains of Q705 and Q708 without an intermediate buffer amplifier. This is possible because of the lower impedances present at the drains of Q703 and Q708.

(4) The input offset voltage of Q704 is cancelled by adjustment of R710 and R719. The input bias currents required by Q704 are supplied by current generators composed of Q701 and Q702 for one input, and Q709 and Q710 for the other input.

(5) The reference voltage generator unit is also a servo-mechanism in each of its three modes of operation. In the first mode to be discussed, the NULL mode, the feedback loop is completed through the operator. In this mode, the high gain amplifier is used as a null detector between the slider of R703, the six place divider, and the top of the bridge. Small differences in potential between those points result in a very small current flowing into one amplifier input and out the other. This current is amplified by Q704 and integrated by Q713 in capacitor C705. The net charge on C705 is indicated on the front panel meter M701. A sufficient condition for a null to exist between the slider of R703 and the top of the bridge is that the charge on C705 remain constant. Thus, it is not necessary to bring the output voltage meter pointer to zero in order to obtain a null in the dials of R703. It is only necessary that the pointer be stationary at some point between plus and minus 10 volts. In the null mode, S702 is nonfunctional in the ΔV position. In the V position, the bridge voltage is presented at terminals 21 and 22.

(6) In the reference generator or RVG mode, the operational amplifier described above is modified by the addition of Q715, which serves as a power amplifier. In this mode, the operational amplifier is connected as a unity gain voltage follower. This is accomplished by returning the output of the amplifier from Q715 to the inverting input, terminal E1. The non-inverting input, terminal E2, then presents a very high impedance to the divider R703. This avoids loading errors. With proper adjustment of the two bias current compensating circuits, the input impedance so the voltage follower configuration exceeds 1000 megohms. The maximum output impedance of the voltage divider is on the order of 3000 ohms so that the loading error due to the voltage follower

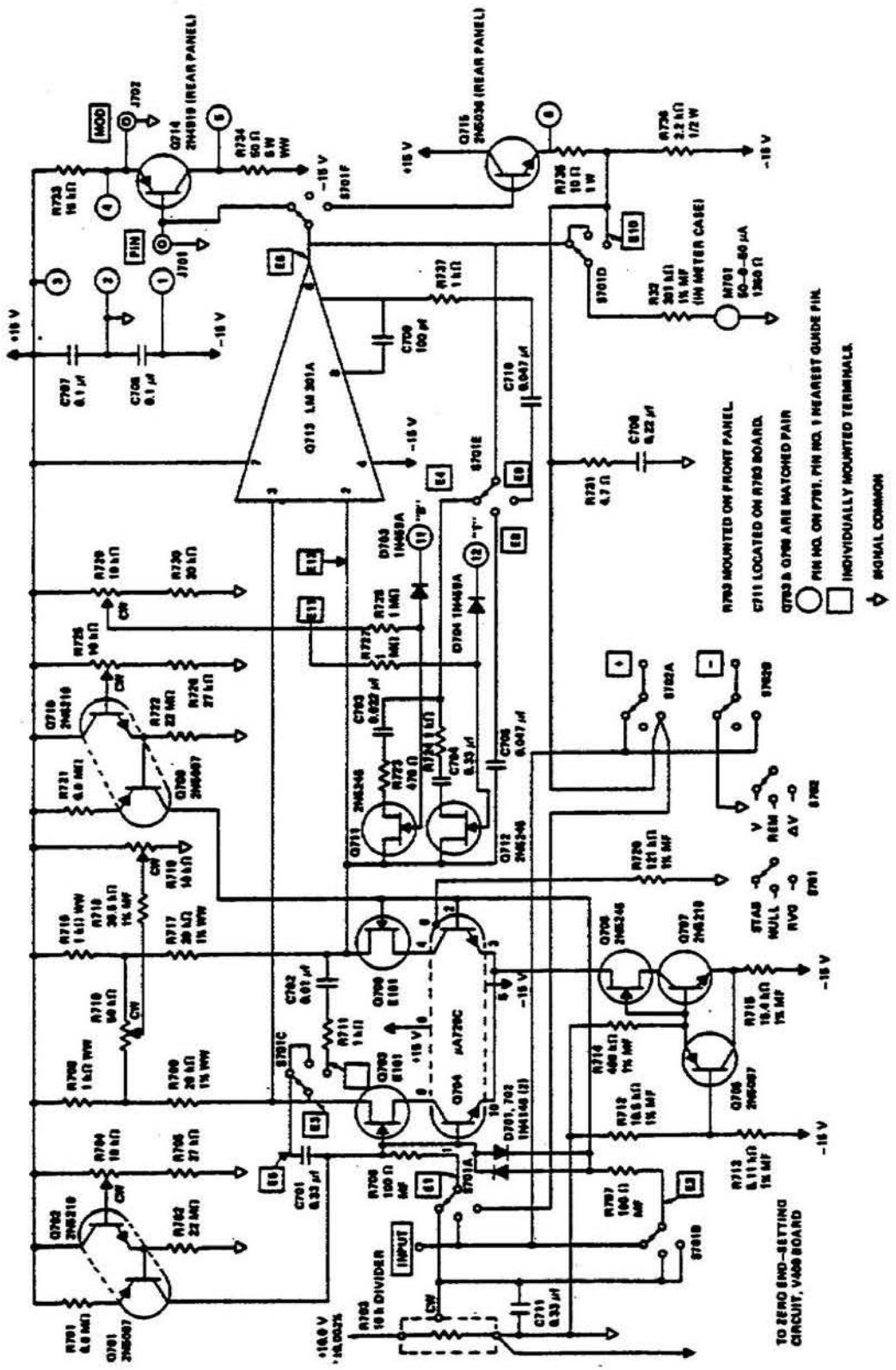


Figure 13. Reference generator amplifier.

will generally be less than 3 ppm. At the same time, the closed loop gain of the voltage follower is very nearly equal to 1. Thus, the voltage which appears at the slider of R703 is presented at terminal 22, but whereas the impedance of slider R703 may be several thousand ohms, the action of the unity gain voltage follower reduces the effective impedance at terminal 22 to a very small fraction of an ohm. Useful currents may be draws from this terminal without serious loading errors. The actual output impedance is on the order of 20 milliohms and consists primarily of the switch and binding post resistances. It can be seen, therefore, that the voltage measuring instrument used to measure ΔV need not have a very high input impedance because it is measuring the voltage between two zero impedance sources. This also minimizes the errors due to source resistance unbalance which appear in certain types of digital voltmeters.

(7) The operational amplifier, connected as a unity gain voltage follower, requires AC stabilizing. This is accomplished by R711 and C702, by R737 and C710, and by R731 and C706. The output voltage meter M701 again indicates the output of the reference voltage generator.

(8) The maximum current which may be drawn from terminal 22 is given by the equation in the specifications Table 1B. In any case, the output current is limited by the current limiting circuitry in the +15 volt power supply to protect the components in the instrument.

(9) In the third (STAB) mode of operation, the instrument may be used as a precision power stabilizer. This configuration resembles that of the all mode except that the output of the operational amplifier is used to drive a modulator in the microwave transmission line. The voltage at the top of the bridge is compared with the voltage at the slider of R703 and the difference is amplified by the operational amplifier to drive a PIN diode modulator, or, through a unity gain power amplifier, a ferrite modulator. The output for the PIN modulator is takes directly from Q713 in order to protect the modulator. This output current is limited to approximately 5 mA or less. The output for a ferrite modulator is taken from the emitter of Q714. Both signals go negative when higher attenuation is required by the servo loop. The current available from Q714 is limited by R734 and by the current limiting circuitry in the -15 volt power supply. In this mode of operation, the RF level is set with divider R703.

(10) The operational amplifier in the stabilizer mode requires AC compensation. This is afforded by the networks switched by Q711, Q712, and C701. The appropriate network of the two switched by the field effect transistors is selected by the barretter-thermistor switch on the bridge unite with the switching signal carried to the reference generator unit through the rear connecting cable. It should be noted that if the reference voltage generator is to be used as a stabilizer with external ±15 volt power supplies instead of a bridge unit, the appropriate control signals for these analog switches must be provided to insure stable operation. Because of the location of the switching transistors Q711

and Q712, it is necessary to provide a pre-bias from R729 and R730. It is important that this adjustment be made before any other adjustment in the reference voltage generator unit.

h. ±15 Volt Power Supply Circuit Description.

(1) Concerning the P100 boards, all of the power supplies required by the bolometer bridge in the reference voltage generator units are contained in the bolometer bridge unit. These consist of two identical printed circuit boards labeled P100 (refer to Figure 14). Terminals 14 and 15 are connected to transformer T1 as indicated in Figure 15. The AC input power is rectified by D105 through D108 and filtered by C105. The load current then flows from C105 through current sensing resistor R104 to pass-transistor Q111 mounted on the rear panel of the bridge unit.

(2) An auxiliary power supply consisting of D101 through D104 provides +30 volts for use within the P100 board and for the V400 board. With a 117 volt power line, approximately 60 volts appears on the collector of Q101. Transistor Q102 compares a sample of the voltage which appears at the emitter of Q101 with the drop across zener diode D109. As the emitter voltage of Q101 rises, the conduction of Q102 increases, increasing the drop across R103 and decreasing the emitter voltage of Q101. This maintains the output of the +30 volt supply at nominally 30 volts. The trimmer, R108 is used to set the output voltage.

(3) The voltage reference element for the +15 volt power supply is Q108. It requires a constant current bias. This is supplied by a constant current source composed of Q106 and Q107. Q106 and Q107 are complementary transistors, cemented together for temperature tracking. The collector current of Q107 is determined by the voltage drop across R114 and the voltage on the base of Q107. Thus, the two base emitter drops cancel each other, and, to the extent that they remain equal with temperature, the current through Q107 will be independent of the temperature. The reference voltage for the current generator is provided by diode D110, which is itself a temperature compensated zener element.

(4) Transistor Q108 is a hybrid device which combines an amplifying transistor with a zener diode in the same case. The unit is designed so that the positive temperature coefficient of the zener element is compensated by the negative temperature coefficient of the base-emitter diode drop of the transistor element. A sample of the output voltage appears at the slider of R118 and is compared with the sum of the zener diode drop and the base-emitter drop of the transistor. The collector load impedance for Q108 is the constant current source discussed above, and consequently the voltage gain at this stage is very high, typically about 1000. The collector of Q108 is connected to a three stage Darlington amplifier composed of Q109, Q110 and the pass transistor Q111 on the rear panel. The output voltage is set by adjustment of R118. Clockwise rotation causes an increasing output voltage. The output voltage is also presented to Q105. Resistor R112 is selected so that Q105

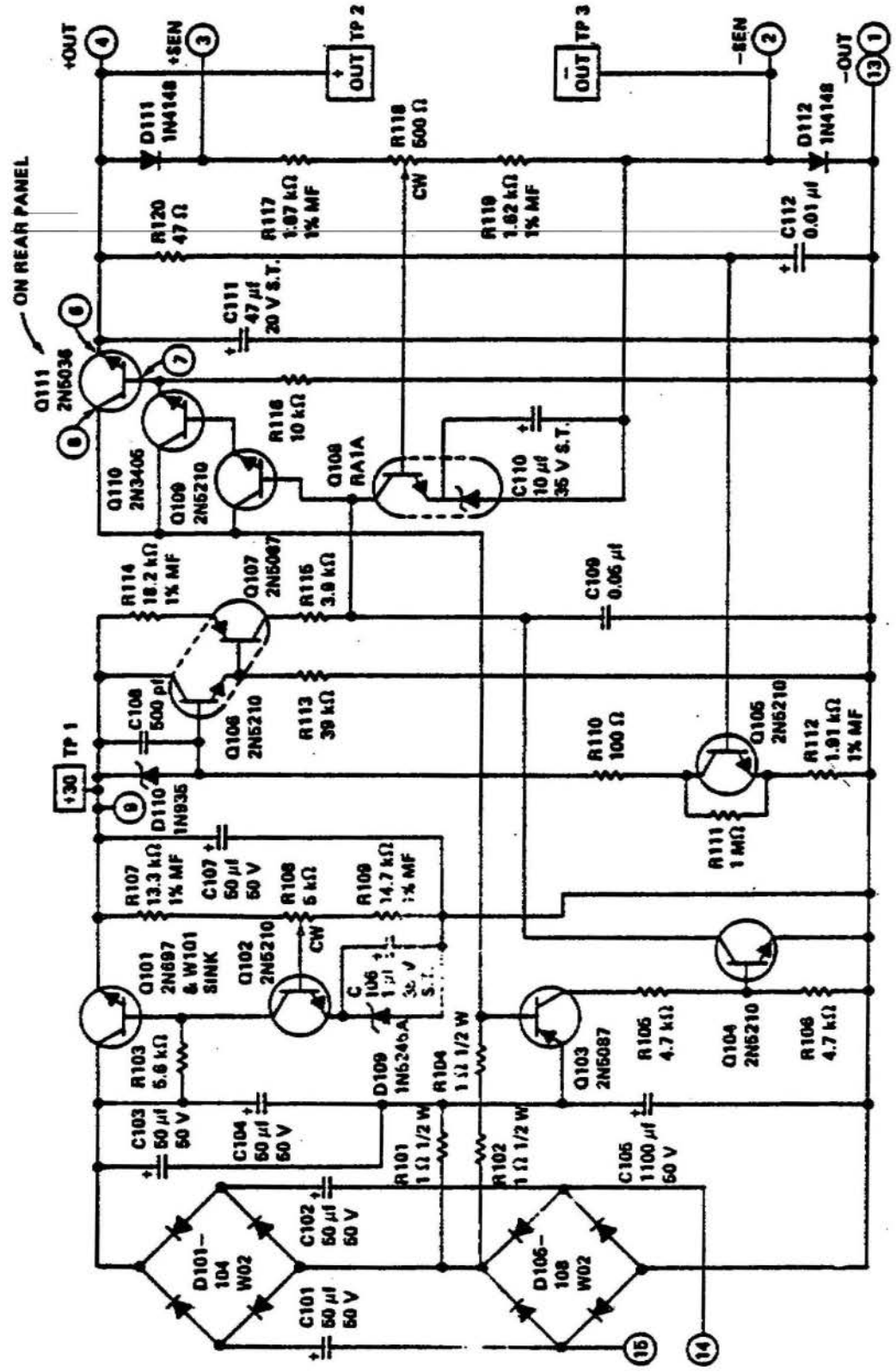


Figure 14. ±15 volt power supply schematic.

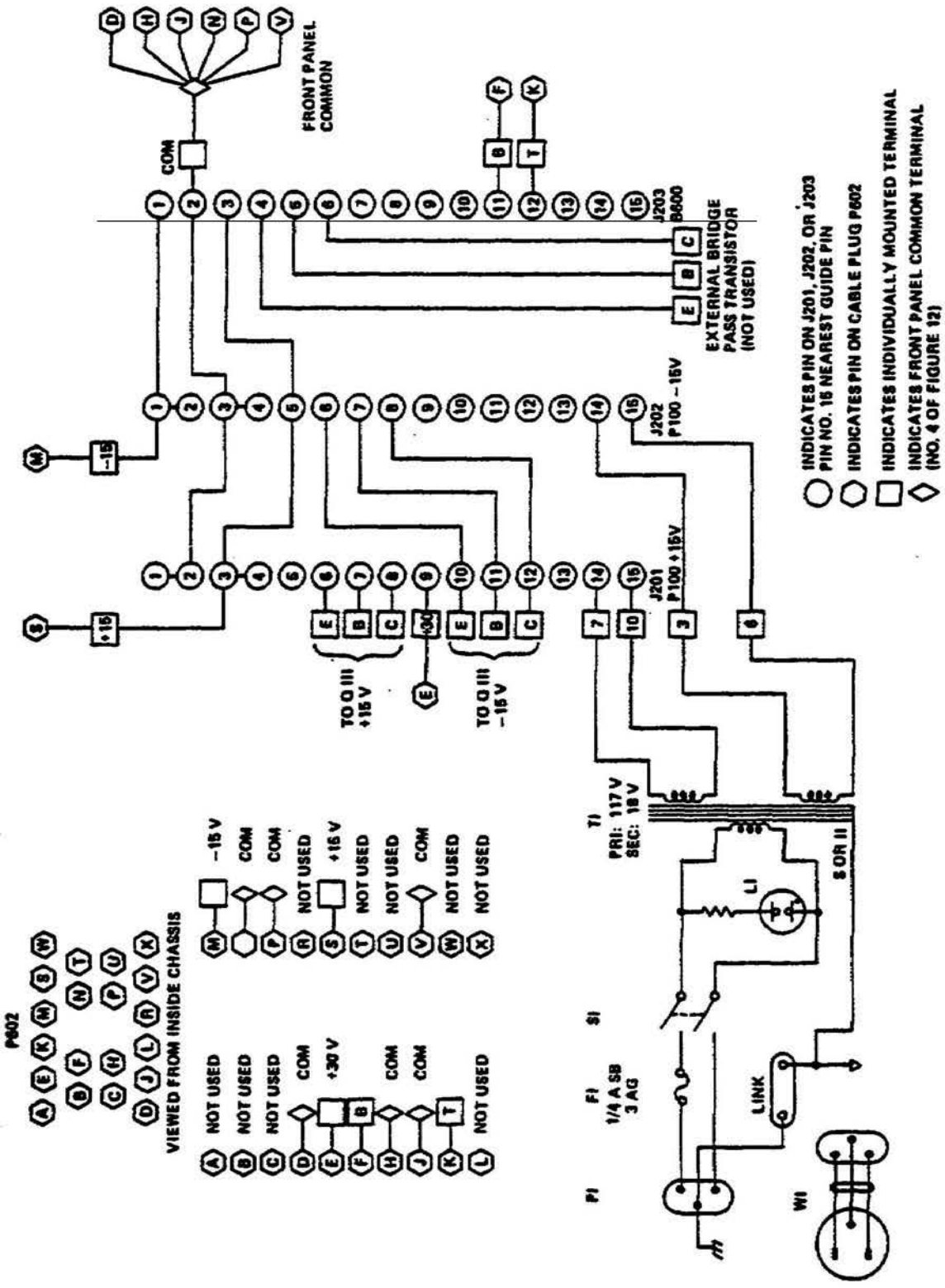


Figure 15. M200 bridge mother board schematic.

will provide the proper operating current to D110. R111 by-passes Q105 to provide enough signal to D110 to permit the power supply to turn on.

(5) The voltage drop across R104 developed by the load current will cause Q103 to conduct if the drop exceeds approximately 0.5 volts. This in turn causes Q104 to conduct, and Q103 and Q104 together comprise a high gain DC amplifier. As Q104 conducts, current from Q107 is diverted from Q108 to the negative output line. This results in sharp current limiting at the point where Q103 first begins to conduct.

(6) The P100 printed circuit board was designed for general purpose applications which might require remote sensing. In this instrument, the output voltage is sensed on the motherboard side of the connector rather than on the P100 side. Diodes D111 and D112 are included for possible applications where opening one of the sense lines might result in an over-voltage condition which could damage the attached equipment.

i. 10 Volt Precision Reference Supply Circuit Description. The +10 volt supply on the V400 printed circuit board (see Figure 16) is essentially identical to the +15 volt regulator described in Paragraphs 7h(3) and 7h(4). The +15 and the +30 volts for the 10 volt regulator are obtained from the +15 volt P100 board. A lower temperature-coefficient reference element, Q404, is used. The temperature coefficient of Q404 may be further improved by adjusting its collector current through selection of R405. As Q404 is temperature cycled, R405 is chosen from a range of values lying between 20K ohms and 287K ohms to give the best overall temperature coefficient. Since the output of this reference supply must be set to better than ±10 ppm, a more elaborate divider string, R409 through R418, is required. The values of R409, R410, R415, and R416, and the position of R417 and R418, can only be determined after knowing the exact value of the reference element voltage. This may be determined after the collector current is set for a minimum temperature coefficient. Short circuit protection is provided by current limiting of the +15 volt supply.

8. POWER STANDARDS SET.

a. Description.

(1) The Power Standards Set consists of six power standard assemblies cushioned with a foam insert and packaged in a lightweight container. The power standard assemblies consist of either a waveguide or coax high directivity directional coupler and thermistor mount. The thermistor mount is attached and sealed to the coupled output of the directional coupler. The foam insert acts as a cushion and protects the power standard assemblies from damage during transportation. The container protects the power standard assemblies from environmental conditions during transportation and storage and forms a convenient shipping container.

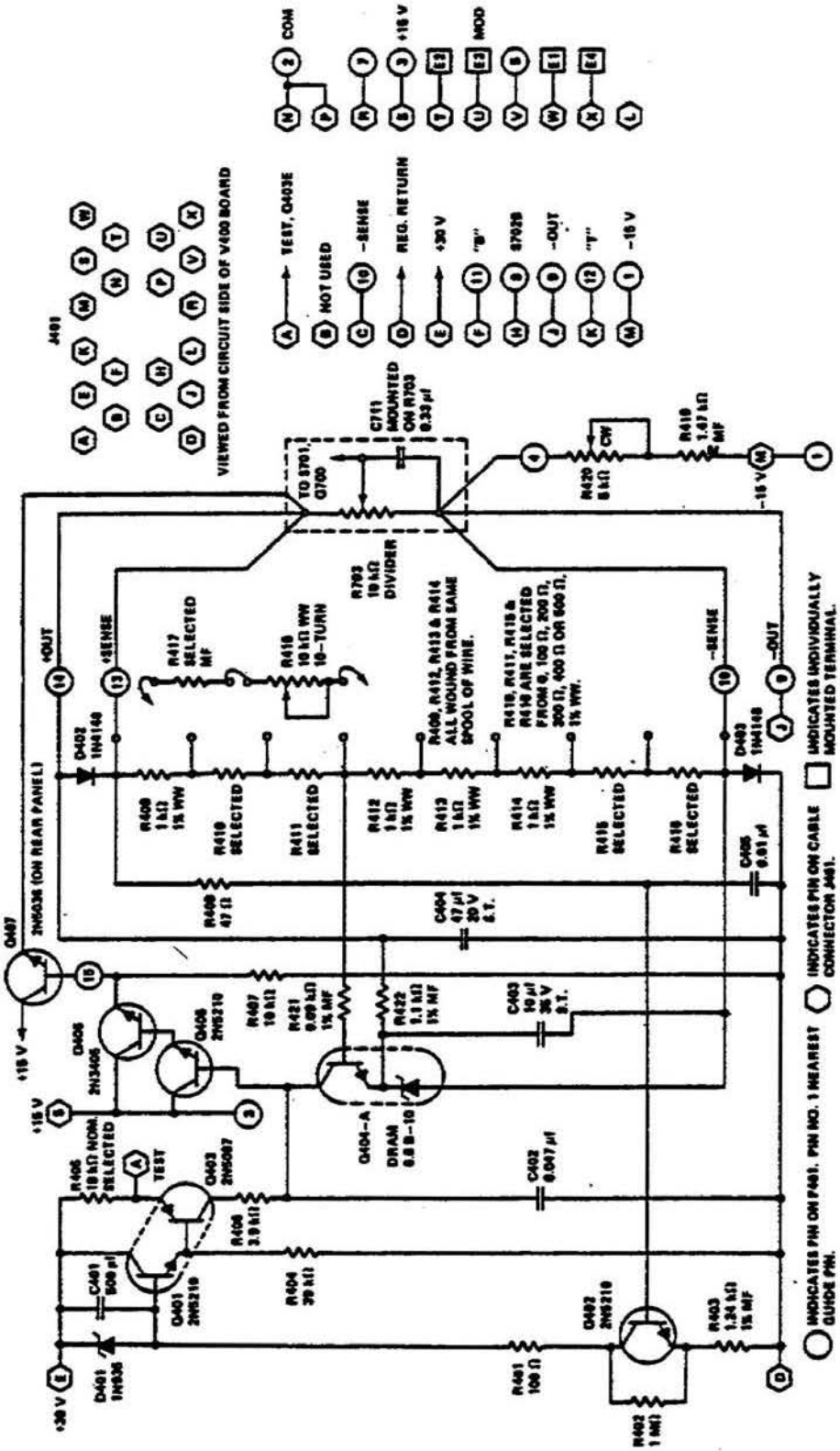


Figure 16. V400A precision 10 volt power supply schematic.

(2) The directional coupler used in the Waveguide Power Standard Set consists of two waveguide sections, the main guide and auxiliary guide, bonded together along their broad surfaces. One end of the auxiliary guide has a built in matched termination. The other end has a flanged port. An array of holes in the common wall between the two waveguides transfers power from one guide to the other. Power entering at the input of the coupler flows along the main guide and divides at the coupling array. Part is coupled into the auxiliary guide, the rest continues along the main guide.

(3) The amount of power coupled into the auxiliary guide depends on the coupling factor. The directional coupler used in the coaxial power standard assemblies consists of two quarter wave coaxial transmission lines capacitively coupled. One end of the auxiliary coaxial line has a built in termination. The power flow through the coupler is analogous to that of the waveguide coupler. Individual calibration reports are supplied for the couplers in the power standard assemblies. The thermistor mount provided in the coaxial power standard assemblies is designed for use with Model 431 and 432 Power Meters to measure microwave power from 1 μW to 10 mW. Design of the mount minimizes adverse effects from environmental temperature changes during measurement. For increased measurement accuracy, effective efficiency and calibration factor are measured for each mount, and at selected frequencies across the operating range; the results are marked on the label of the instrument. The unit can be used over the 10 MHz to 10 GHz frequency range. Throughout the range, the mount terminates the coaxial input in a 50 ohm impedance, and has a standing wave ratio (SWR) of not more than 1.75 without external tuning.

(4) Each mount contains two series pairs of thermistors, which are matched to cancel the effects of drift with ambient temperature change. Thermal stability is accomplished by mounting the leads of all four thermistors on a common thermal conductor to ensure a common thermal environment. This conductor is thermally insulated from the main body of the mount so the thermal noise or shocks applied externally to the mount, such as those from handling the mount manually, cannot significantly penetrate to disturb the thermistor. This thermal immunity enables the thermistors to be used in the measurement of microwave power down to the microwatt region.

(5) The thermistor mounts provided in the waveguide power standard assemblies are designed for use with the Model 431 and 432 power meters in the measurement of microwave power from 1 μW to 10 mW in the range from 8.2 to 18 GHz. Design of power mater and thermistor mount is such that the measurement system is temperature-compensated. This feature permits microwave power measurements that are relatively free of the drift in meter indication that otherwise occurs with changes in ambient temperature.

(6) For improved accuracy of measurement results, calibration factor and efficiency are measured at selected frequencies across the

operating range of each mount, and the results recorded on the label of the mount. In addition, each mount is tested on a swept-frequency basis to assure that interpolation between measured points is valid.

(7) A detection thermistor is mounted within the mount's shorted waveguide section and is located so that it samples the E field and provides an optimum match across the band. As it absorbs RF power, its temperature (and therefore its resistance) attempts to change. However, the RF bridge circuit is self-balancing and reduces thermistor bias current to maintain the thermistor's proper operating resistance. Since the amount of bias change is proportional to incoming RF power, it is measured and used to indicate the RF power absorbed by the mount.

b. Specifications. The following tables provide the specifications for the power standard assemblies and directional couplers which are used in the assemblies. The specification for individual thermistor mount is covered in lesson 3. Table 5 shows which directional couplers and thermistor mounts go into the individual power standard assemblies, and the assembly number is provided for reference.

(1) Not separately specified. Variation allowed is included in accuracy.

(2) About mean coupling which is the average of maximum and minimum coupling in the rated frequency range.

(3) Port A is main line input, Port B is main line output, and Port C is secondary line output.

Table 3. Specifications

Power Standard Assy.	Freq. Range	Power Range	Flange/ Connector	Insertion Length in.
SK–D–4850–18–1	0.5– 1.0 GHz	10 microwatts to 100 milliwatts	N–Female	11.5
SK–D–4850–18–2	1.0– 2.0 GHz	10 microwatts to 100 milliwatts	N–Female	8.5
SK–D–4850–18–3	2.0– 4.0 GHz	10 microwatts to 100 milliwatts	N–Female	7.5
SK–D–4850–18–4	4.0– 8.0 GHz	10 microwatts to 100 milliwatts	N–Female	8.5
SK–D–4850–18–6	8.0– 12.4 GHz	10 microwatts to 100 milliwatts	UG39/U	15.687
SK–D–4850–18–7	12.4–18.0 GHz	10 microwatts to 100 milliwatts	UG419/U	12.250

Table 4. Directional Couplers and Accuracy

Directional Coupler (1)	Freq. Range GHz	Nominal Coupling	Coupling Accuracy	Coupling Variation	Directivity (min), db	Max. VSWR (4) Port A & B	Port C
4037B	0.5–1.0	10db	±1.2db	(2)	42	1.06	1.10
4031B	1.0–2.0	10db	±1.2db	(2)	40	1.08	1.10
4032B	2.0–4.0	10db	±1.2db	(2)	38	1.10	1.15
4033B	4.0–8.0	10db	±1.2db	(2)	33	1.15	1.20
X410C	8.2–12.4	10db	±0.4db (3)	±0.5db	40	1.05	1.15
P410C	12.4–18.0	10db	±0.4db (3)	±0.5db	40	1.05	1.15

Table 5. Thermistor Mounts and Couplers Used With

Power Standard Assy. APN	Directional Coupler (1)	Thermistor Mount (5)	MMC Assembly No. Ref.
SK–D–4850–18–1	4037B	HP–478A	MT9024–20–1
SK–D–4850–18–2	4031B	HP–478A	MT9024–20–2
SK–D–4850–18–3	4032B	HP–478A	MT9024–20–3
SK–D–4850–18–4	4033B	HP–478A	MT9024–20–4
SK–D–4830–18–6	X410C	HP–X486A	MT9024–20–6
SK–D–4850–18–7	P410C	HP–P486A	MT9024–20–7

c. Equipment Supplied.

(1) 1 - Power Standard Assembly, SK-D-4850-18-1 (P/N MT9024-20-1).

(2) 1 - Power Standard Assembly, SK-D-4850-18-2 (P/N MT9024-20-2).

(3) 1 - Power Standard Assembly, SK-D-4850-18-3 (P/N MT9024-20-3).

(4) 1 - Power Standard Assembly, SK-D-4850-18-4 (P/N MT9024-20-4).

(5) 1 - Power Standard Assembly, SK-D-4850-18-6 (P/N MT9024-30-6).

(6) 1 - Power Standard Assembly, SK-D-4850-18-7 (P/N MT9024-30-7).

(7) 1 - Adapter, Model 11528A.

(8) 1 - Case, SK-681000 (P/N MT9024-11).

(9) 1 - Cushion Insert, SK-D-4850-19 (P/N MT9024-12 and -13).

d. Application.

(1) The Power Standards Set contains power standard assemblies which are basic instruments for precision microwave power measurements and as a means to accurately monitor power in a circuit without terminating all of the power in the measuring device. These devices are used as a standard of comparison for calibrating other power measuring devices connected to the coupler main arm output or for any case of making accurate-in-line measurements of incident power. The basis of a power standard assembly as shown in Figure 17 is the "Power Standard Calibration Factor" defined as:

$$Kc = \frac{Pdc\ substituted}{P\ \mu wave\ incident}$$

(2) Where Pdc substituted is equal to DC power substituted in the thermistor element and P μwave incident is equal to microwave power incident to a non-reflective load terminating the coupled main arm output.

(3) The thermistor mount is of the broadband variety, and is attached to the auxiliary arm of a high directivity directional coupler as shown in Figure 17. The calibration factor, Kc, is measured at specific frequencies within the band and includes the effects of mismatch between thermistor mount and coupler auxiliary arm, and the bolometer mount efficiency.

(4) When Kc is known for the power standard assembly, it is then possible to determine an unknown incident power by measuring Pdc substituted.

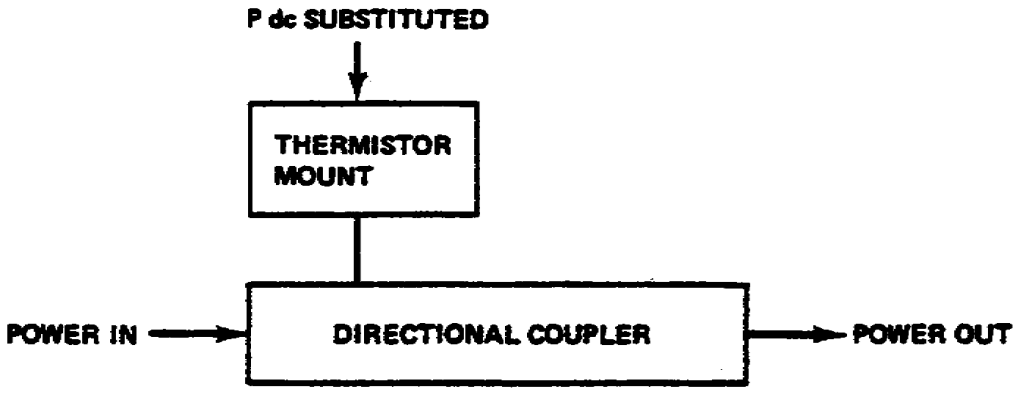


Figure 17. Power standard assembly.

AIPD SUBCOURSE MM0474, POWER MEASUREMENT
EXERCISES FOR LESSON NUMBER 4

1. What is the purpose of NBS Type II Power Measuring System?

   a. Measure low frequency power
   b. Measure high frequency power
   c. Calibrates power meters

2. The frequency and power range covered using the Type II Power Measuring System depends upon

   a. The bolometer used
   b. Output voltage
   c. The external voltmeter used

3. When the reference generator is operating in the RVG mode, the output voltage meter displays

   a. The output of the null detector amplifier
   b. The setting of the decade divider dials
   c. The output of the leveling amplifier

4. In addition to determining a bolometer's operating resistance for use with the Type II Power Measurement System, what other factor should be determined?

   a. Operating voltage
   b. Power level
   c. Whether it is a barretter or thermistor

5. Before the bolometer mount is connected to the bridge on the power measurement system

   a. With power off, set the BARR-THER switch
   b. Turn power on and let the instrument stabilize
   c. Disconnect the rear grounding link

6. A precision power measurement using the power measurement system requires an external

   a. Precision voltage source
   b. Voltmeter
   c. Current meter

7. In the measurement procedure of the power measurement system, drift in the null is caused by

   a. A thermal drift of the bolometer element
   b. A drift of the RF power source
   c. Sensitivity of divider dial

8. In addition to the reference generator being used as a stable voltage source, it can be used as a

   a. Precision current meter
   b. Power meter
   c. Power stabilizer

9. In the bolometer bridge, if the element is a barretter, what happens to the resistance as RF power is applied to the bolometer?

   a. Resistance will increase
   b. Resistance will decrease
   c. Resistance will remain the same

10. What stabilization is required in the operational amplifier when connected as a unity gain voltage follower?

    a. DC
    b. AC
    c. RF

11. In the reference generator, the output current is limited by the current limiting circuit of which power supply?

    a. +15 volt
    b. -15 volt
    c. +30

12. Why are Q106 and Q107, as the constant current source in ±15 volt power supply circuit, complementary transistors?

    a. For current gain
    b. For impedance matching
    c. For temperature tracking

13. What is the voltage reference element for the +15 volt power supply?

    a. Q111
    b. Q108
    c. D109

14. What determines the amount of power coupled into the auxiliary guide of the power standards set?

    a. Power from the source
    b. Thermistor mounts
    c. Coupling factor of the waveguide

15. The thermistor mount in the power standards set can be use over the 10 MHz to 10 GHz frequency range, what is the termination impedance of the mount?

    a. 50 ohm
    b. 75 ohm
    c. 1K ohm

16. How is the thermistor mounts in the power standards set tested to assure that interpolation between measured points is valid?

    a. Checked at maximum power
    b. Tested micro watt range
    c. Tested on a swept-frequency basis

17. For a precision power stabilizer arrangement, what does the reference generator amplifier compare the voltage at the top of the bridge with?

    a. Reference voltage set by a divider
    b. +10 Volt reference
    c. Pin modulator output

18. Where does the reference generator obtain its operating voltages?

    a. Its own power supply
    b. From the bridge
    c. An external source

19. The power measuring system measures microwave power in terms of

    a. Substituted DC power
    b. Substituted AC power
    c. Direct readout

20. The external modulator used with the reference generator for precision power stabilizer can either be a PIN diode or a ferrite type, why is the PIN output only 5 mA maximum while the MOD output is 300 mA maximum?

    a. To develop a power shift
    b. To protect the PIN diodes
    c. To protect the reference generator

LESSON 5. POWER MEASUREMENT TECHNIQUES

AIPD Subcourse Number MM0474.....Power Measurements

Lesson Objective.....After studying this lesson you will know the techniques of power measurements and the procedures on how to calibrate power measuring devices.

Credit Hours.....Two

TEXT

1. INTRODUCTION.

a. The basic concept of power is the same for microwave as for low frequencies; however, the practical aspect of the two are quite different. For instance, in most circuits, power can be specified and measured in terms of voltage across the circuit and the current flowing through the circuit as a result of such voltage. In microwave, power measurements are made in the milliwatt region by the bolometric and thermistor methods. These concepts find wide application in measurements of attenuation, transmission losses, and related subjects.

b. In previous lessons, the equipment used for power measurements are discussed. In this lesson you will learn the techniques and use of the power measuring equipment for making power measurements and calibration of thermistor mount.

2. POWER MEASUREMENTS USING THE MODEL 431C/432A POWER METER.

a. RF power measurements are performed using the setup shown in Figure 1. The power meter is used with one of five thermistor mounts that collectively cover the frequency range from 0.5 to 40 GHz. Power levels above 10 mW can be measured by inserting a suitably calibrated attenuator between the thermistor mount and power source.

b. Procedure

(1) A typical equipment connection for power measurement using the model 431C/432A is shown in Figure 1.

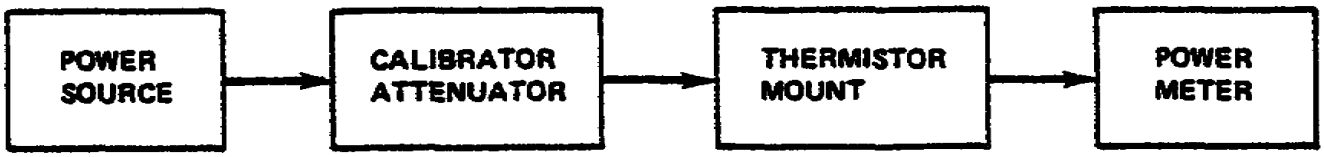


Figure 1. Typical power measurement connection.

(2) Power meter controls should be set to the following settings with the power source operating in CW mode.

(a) MOUNT RESISTANCE switch to the position corresponding the thermistor used.

(b) RANGE switch to 0.01 mW.

(c) ZERO and NULL controls to null meter as you learned in a previous lesson.

(d) RANGE control to required position and CALIB FACTOR to position stamped on label of thermistor mount.

c. Techniques

(1) Connect bolometer to source.

Note. Make sure power out of source is less than maximum capability of the setup.

(2) Power is read on meter in mW (or dBm if referenced on 1 mW range).

3. CALIBRATION OF MODEL 431C POWER METER USING THE MODEL 8402 B CALIBRATOR.

a. Principle.

(1) Apply known DC current from an external DC power source. The 8402B calibrator can be used for this purpose also:

(2) Power meter should read full scale on range selected.

(3) Adjust controls on model 8402B to less than full-scale cardinal points.

(4) Meter should track in accordance with indicated value on 8402B.

b. Procedure

(1) Equipment should be connected as in DC substitution, Figure 2.

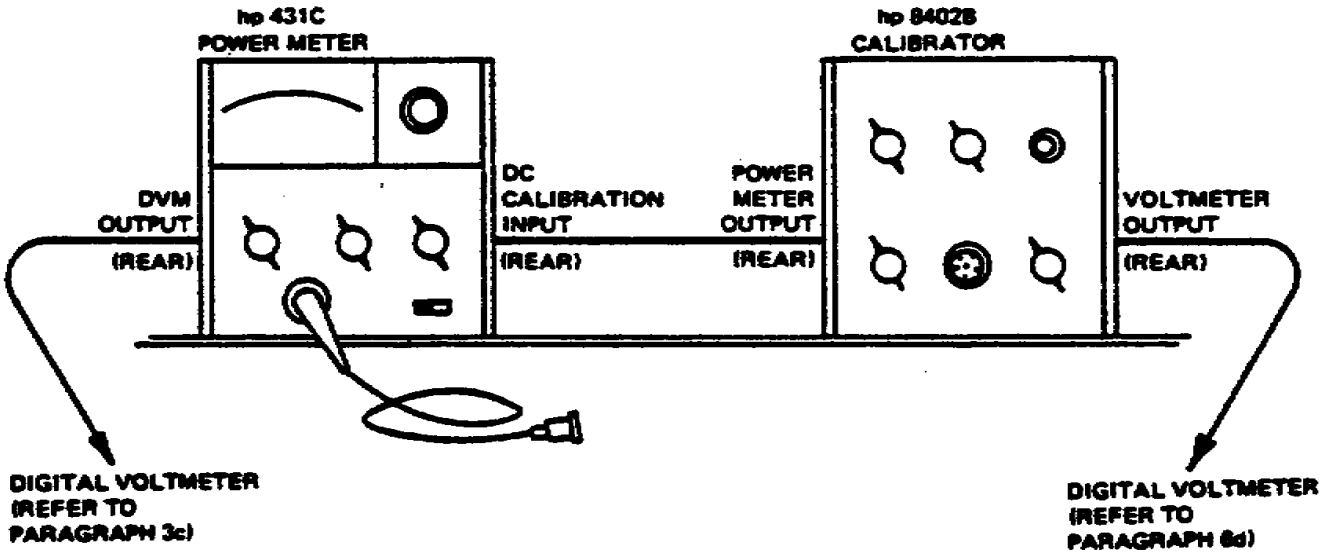


Figure 2. Calibration of model 431C power meter.

(2) Technique.

(a) Zero and Vernier check.

1. Connect DVM to DVM Output of 431C.

2. Set MOUNT RES switch of H-P 431C to correspond to mount in use.

3. Turn RANGE switch of 431C to 0.01.

4. Adjust zero control for 0.00 VDC on DVM.

5. Turn RANGE switch of H-P 431C through ranges of 0.03, 0.1, 0.3, 1, 3, and 10 mW. Voltmeter indication should remain between -0.01 and +0.01 VDC. If not, adjustment must be made.

(b) Range and Tracking.

1. Position controls of H-P 8402B as indicated below:

Function switch to current off.
Mount resistance to correspond to mount in use.
Current and vernier fully CCW.

2. Connect power meter terminals of power meter calibration terminals of H-P 431C.

3. Set mount res switch of 431C to correspond to mount in use.

4. Set H-P 8402B and H-P 431C Range switches to some reading.

5. Place function switch of H-P 8402B to calibrate.

6. H-P 431C should indicate full scale.

7. When 10 mW range is reached, continue adjusting range on 8402B to 8, 6, 4, and 2 mW positions. H-P 431C meter should track at these readings. If not, meter movement is defective.

4. POWER MEASUREMENT USING H-P 431C POWER METER WITH THE H-P 8402B CALIBRATOR (DC SUBSTITUTION).

a. Measurement principles.

(1) Apply the RF power to the thermistor mount and note the power meter reading.

(2) Remove the RF power and substitute a DC current from an external DC power source to precisely duplicate the reading obtained.

(3) Calculate the power from the substituted DC current and thermistor operating resistance.

b. Procedure.

(1) Equipment connection, see Figure 2.

(2) Technique.

(a) Operate signal source in CW mode (leveled).

(b) Set RANGE switch on power meter to 10 mW and adjust level set attenuator for full-scale reading on power meter. Record corresponding reading on digital voltmeter.

(c) Turn HI volt switch on signal source to off.

(d) Turn on power meter calibrator by setting FUNCTION switch to current off; then apply a substitution current by setting FUNCTION switch to substitute and adjusting current controls until reference reading is obtained on digital voltmeter.

(e) Note and record indication on digital voltmeter. On the 0.01-, 0.03-, 0.1- and 0.3 mW ranges this is the substitution current IDC in mA. On all other ranges multiply by 10 to obtain IDC in mA.

(f) Disconnect thermistor mount from thermistor mount cable. Connect thermistor mount cable between H-P 431C and H-P 8402B calibrator resistance standard connector. Set H-P 431C power meter to null position.

(g) Set H-P 8402B calibrator thermistor resistance control to -0.5% and mount resistance to correspond to resistance and type of thermistor used.

(h) Set H-P 431C range switch on H-P 8402B clockwise until the power meter changes from zero reading to a stable reading above zero. The operating resistance of thermistor (R_d) is nominal value indicated on mount label plus or minus correction indicated by setting of thermistor resistance switch.

(i) Calculate power in mW from this formula

$$\text{PWR (mW)} = \frac{(\text{IDC})^2 \ (\text{RD}) \ 10^{-3}}{4}$$

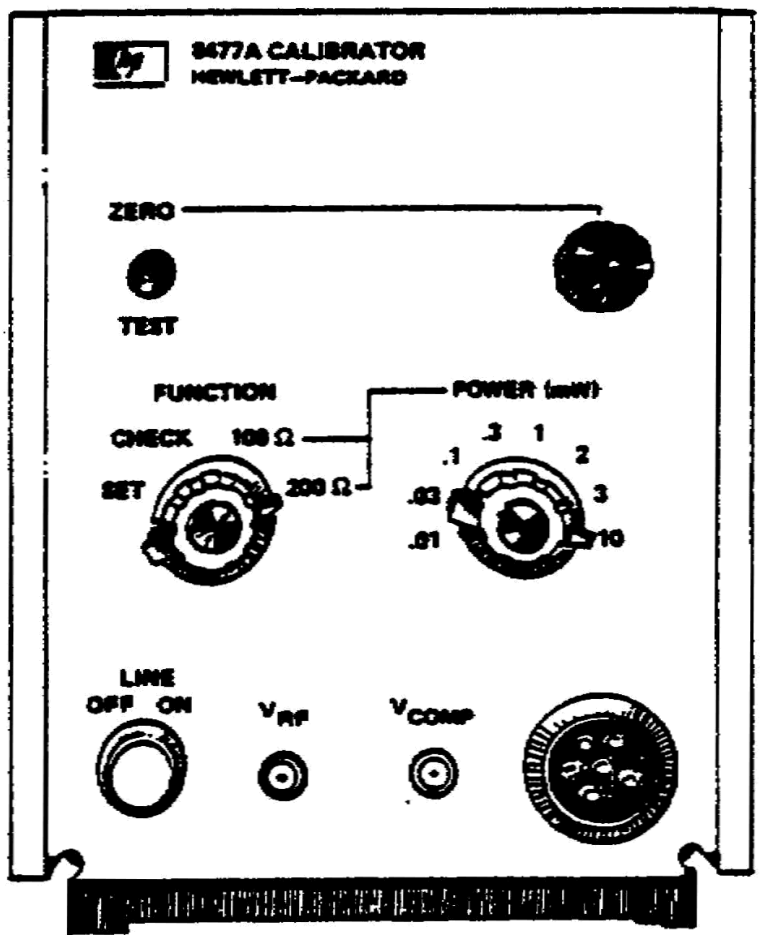


Figure 3. Model 8477A power meter calibrator.

5. CALIBRATION OF MODEL 432A POWER METER.

a. Using a power meter calibrator model 8477A

(1) Principle

(a) Apply known DC power to check meter accuracy.

(b) Power meter should read full scale on range selected.

(c) Adjust controls on model 8477A to check calibration factor, meter linerity and zero carryover test.

(2) Procedure

(a) A typical equipment connection for power meter calibration is shown in Figure 4. If necessary, mechanically zero meter as learned in previous lesson.

(b) Meter accuracy

1. Power meter calibrator controls should be set to the following setting.

a. Line switch to off.

b. Function switch to 200 ohm.

c. Power (mW) switch to .01.

d. Zero/Test switch to zero.

2. Set the test instrument controls as follows:

a. Mount resistance switch to 200.

b. Range switch to 0.1 mW.

c. Calibration Factor switch to 100%.

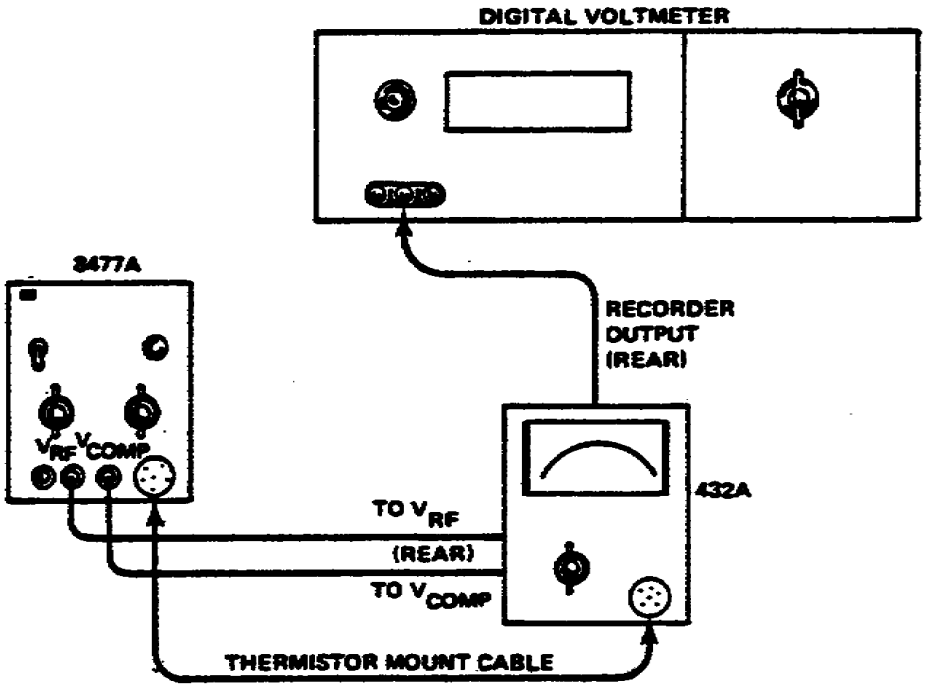


Figure 4. Check and adjustment test setup.

3. After allowing 15 minutes for equipment to warmup, the power meter calibrator should be adjusted for 0 volts on the digital voltmeter.

4. With the calibrator zero/test switch to test and the test instrument range switch to 0.01, the digital voltmeter will indicate between 0.990 and 1.010 volts and the teat instrument will indicate full scale within one-half minor division.

5. The remaining ranges can be checked by setting the switches on the test instrument and power meter calibrator to the respective position.

(c) Calibration Factor

1. Set power meter calibrator zero/test switch to test and the power (mW) switch to 0.1.

2. With the test instrument range switch to 0.1 and the calibration factor switch to 88 percent, adjust the power meter calibrator zero control for 1 volt on digital voltmeter.

3. When the test instrument calibration factor switch is set to the positions listed in Table 1, the digital voltmeter will indicate within the limits specified.

Table 1. Calibration Factor Test.

CALIBRATOR FACTOR SWITCH SETTING	DIGITAL VOLTMETER INDICATIONS (VOLTS)
89	0.979 to 0.999
90	0.968 to 0.988
91	0.957 to 0.977
92	0.947 to 0.967
93	0.936 to 0.956
94	0.925 to 0.945
95	0.916 to 0.936
96	0.906 to 0.926
97	0.897 to 0.917
98	0.887 to 0.907
99	0.879 to 0.899
100	0.870 to 0.890

(d) Meter linearity

1. The test instrument range switch should be set to position 3.

2. With the power meter calibrator power switch in position 1, the test instrument will indicate 1 milliwatt.

3. With the power meter calibrator power switch in position 2, the test instrument will indicate 2 milliwatts.

4. With the power meter calibrator power switch in position 3, the test instrument will indicate 3 milliwatts.

(e) Zero carryover

1. For this test the thermistor mount should be connected to the test instrument while deenergized.

2. After a 15 minute warm up period, set the test instrument range switch to course zero and adjust for a zero indication on the test instrument meter.

3. With the test instrument range switch in position .01, press the test instrument fine zero switch, the test instrument meter should indicate zero.

4. The meter should remain on zero as the range switch is rotated through each position.

5. For this test an oscilloscope can also be used instead of the test instrument meter. It should be connected to the recorder output through a filtering network as shown in Figure 5.

b. Without a power meter calibrator

(1) Meter accuracy test

(a) The test instrument controls should be set to the following positions.

1. Range switch to coarse zero.

2. Mount resistance switch to 200.

3. Calibration Factor switch to 100%.

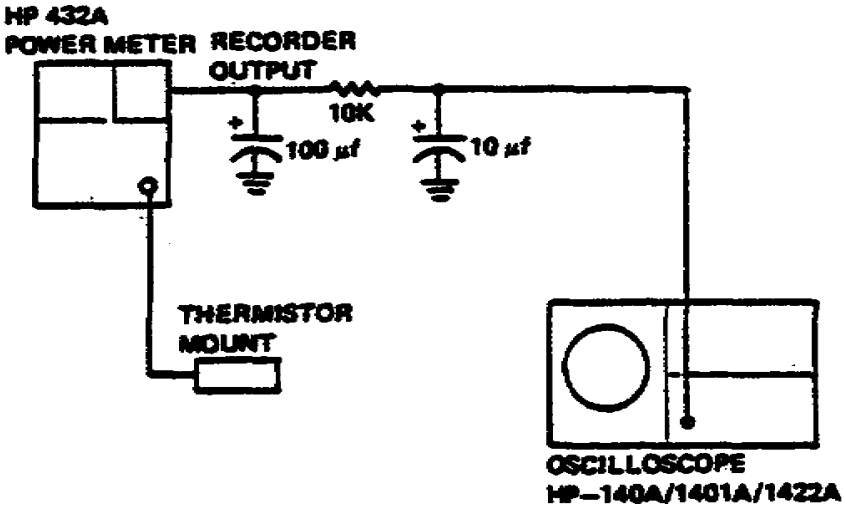


Figure 5. Zero carryover test setup.

(b) With the thermistor mount connected to the test instrument, allow 15 minutes for warmup. The coarse zero control can be adjusted for a zero indication on test instrument meter.

(c) The test instrument meter should indicate zero when the fine zero switch is pressed on Range switch is in position 1.

(d) With the coarse zero control adjust for a 0.9 milliwatt meter indication.

(e) With a digital voltmeter connected to vrf and vcomp center conductors record the digital voltmeter as V1.

(f) Measure and record the voltage between the vrf center conductor and ground.

(g) Measure and record the voltage between the V_{comp} center conductor and ground.

(h) The power can be calculated by substituting the recorded indications in the following formula:

$$P = \frac{(V_1)\ (V_{comp} + V_{rf})}{800}$$

(i) The calculated power should be between 0.89 and 0.91 milliwatts.

(j) Step (d) through (h) can be repeated for each position listed in Table 2.

Table 2. Meter Accuracy Test.

RANGE SWITCH SETTING	METER INDICATIONS (mW)	CALCULATED POWER (mW)
.3	0.3	0.297 to 0.303
3	1	0.97 to 1.03
10	1	0.9 to 1.1

(2) Recorder Output Test

(a) For this test a digital voltmeter should be connected to the test instrument RECORDER output connector.

(b) With the test instrument RANGE switch set to position .1, the coarse zero control should be adjusted for a full scale indication on the test instrument meter. The digital voltmeter should indicate between 0.9995 and 1.005 volts dc.

(3) Calibration Factor Test

(a) With the test instrument CALIBRATION FACTOR switch set to 88%, adjust the coarse zero control for 1.000 volt dc on the digital voltmeter.

(b) Set the CALIBRATION FACTOR switch to positions listed in Table 1. The digital voltmeter will indicate within specified limits for each position.

6. POWER MEASUREMENTS USING NBS II POWER BRIDGE WITH POWER STANDARD ASSEMBLY (MOUNT AND DIRECTIONAL COUPLER).

a. Measurement principles: DC substitution technique is employed to manually match a bridge voltage that has been automatically nulled by integrated circuitry. After match has been accomplished, difference from null condition (no power) is determined, and power is calculated. Overall accuracy obtainable is better than ±.5%.

b. Applications include self-contained power measurement, precision power measurement and reference level thermistor mount calibration factor certification.

c. Procedure for thermistor mount calibration factor (K_b) certification at secondary reference level.

(1) Equipment connections. Figure 6.

(2) Techniques.

(a) Make equipment setup as shown in Figure 6, connection "A".

(b) Set switch to direct power to cavity frequency meter.

(c) Energize signal source and tune for desired frequency as indicated on cavity frequency meter.

(d) Null both NBS II Power Bridges using following procedure:

1. Pre-operation setup.

a. With instrument turned off, set BARR-THER switch according to type of bolometer mount being used. If this switch is not set properly it is possible to destroy a bolometer element, particularly a barretter. Turn instrument off before changing the switch setting.

b. Attach lower links as appropriate for mount operating resistance.

c. Rear grounding link should be in place unless it is necessary to float instrument above ground.

d. Bolometer mount may now be attached to bridge and instrument turned on.

2. Nulling procedure.

Note - This measurement requires the use of an external voltmeter. The accuracy of this voltmeter should be the best possible, since its error contributes directly to the overall measurement error. The voltmeter should be connected to binding posts 21 and 22 located on the lower part of the reference generator.

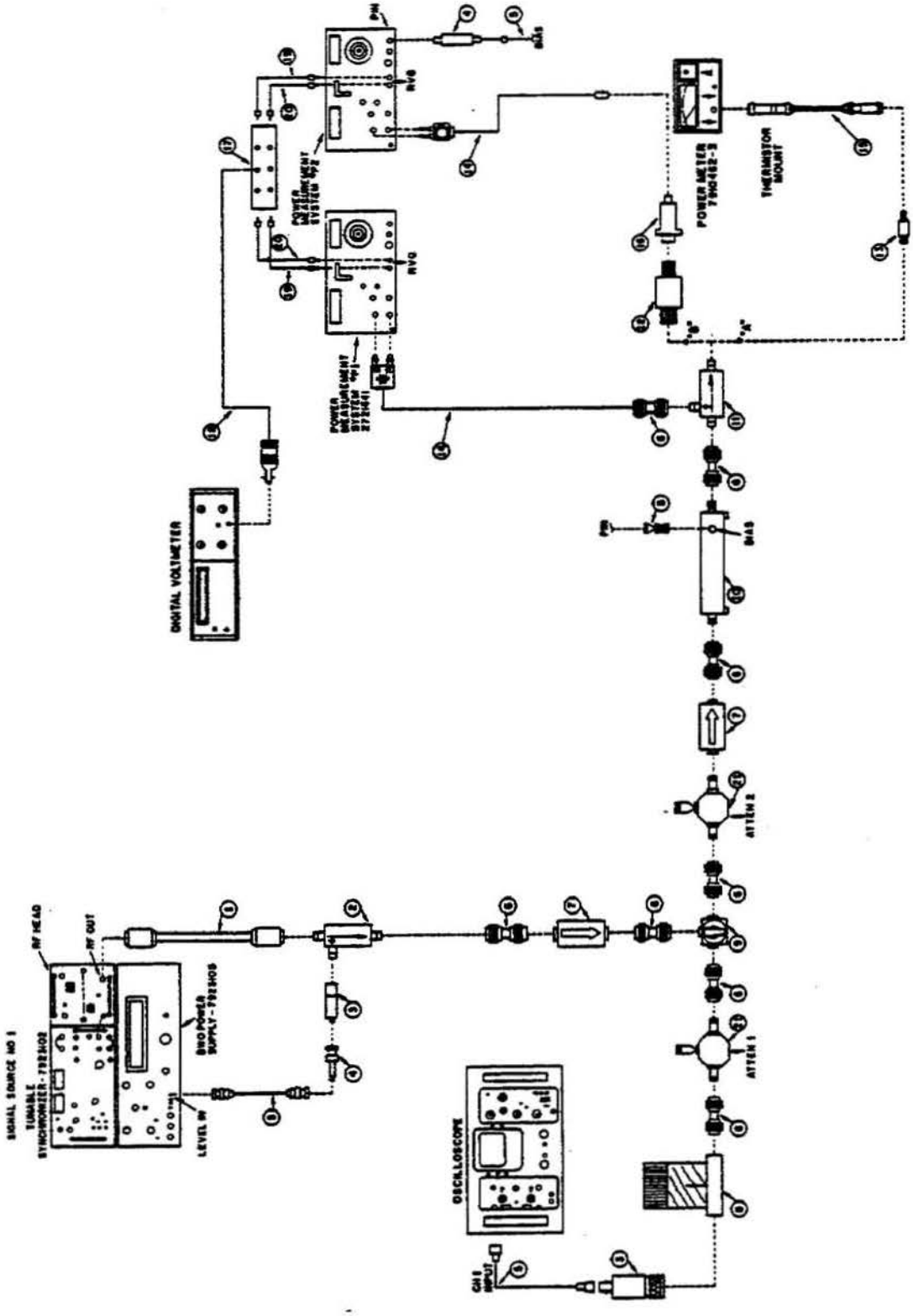


Figure 6. SRS thermistor mount calibration.

a. After preliminary instructions have been followed, turn on bridge and allow a 15 minute warmup period.

b. Bolometer mount should be attached to RF power source, but with RF power off.

c. Place reference generator function switch in NULL position and V-REM-ΔV switch to V. Record DVM reading.

d. Place V-REM-ΔV switch to ΔV function to RVG. Turn main divider dial to indicate reading obtained in c. above and then tune ten-turn dial until DVM indicates 0.0000. This indicates zero difference between bridge and reference generator, i.e., null condition. Null both bridges in the same manner.

e. Place reference generator No. P1 function switch to RVG position (full ccw). V-REM-ΔV to V.

f. Place reference generator No. P2 function switch to STAB position (full cw). V-REM-ΔV to V.

g. Change switch (9) to direct power to the power standard assembly and adjust to 9 mW output as read on 431C.

h. Disconnect thermistor mount and connect uut thermistor connection B.

3. Determining "K_b" factor.

a. Set knife switch (17) to P1 position and switch (9) to POWER ON - Record voltmeter reading as E2 of standard.

b. Turn switch (9) to POWER OFF, record voltmeter reading and record as E_1.

c. Repeat d(1) and d(2) with knife switch in P2 position and record as E_1 and E_2 of uut. Calculate the power using the expression:

$$\frac{K(E_1^2 - E_2^2)}{Kb} = \text{standard mW} \qquad \frac{K(E_1^2 - E_2^2)}{} = \text{uut mW}$$

$$\text{Kb of uut} = \frac{\text{uut mW}}{\text{std mW}}$$

The proper value of K is:

Mount Resistance	K
50 ohms	$\frac{1000}{450} = 2.222$
100 ohms	$\frac{1000}{400} = 2.5$
200 ohms	$\frac{1000}{450} = 2.222$

K_b - cal factor of power standard

Table 3. Equipment Required.

ITEM	NAME
A1	DC Voltmeter
A2	Frequency Meter
A3	Oscilloscope
A4	Power Bridge
A5	Power Meter
A6	Power Standard Kit
A7	Signal Source System
A8	Thermistor Mount

Table 4. Accessories Required.

ITEM	NAME	DESCRIPTION
B1	Adapter	N Plug to N Plug
B2	Adapter	Coaxial to Waveguide
B3	Adapter	Double Banana to BNC
B4	Adapter	Thermistor Mount to BNC
B5	Attenuator	BNC to BNC. 0 to 1 GHz
B9	Crystal Detector	
B10	Directional Coupler	
B11	Isolator	
B12	Termination	50 ohm
B13	Variable Attenuator	
B14	Waveguide Assembly	

7. TRANSFER CALIBRATION TECHNIQUE.

a. The first measurement we will cover is the transfer calibration of a thermistor mount. For signal source operation consult ORD Subcourse 471.

b. Calibration Factor.

(1) Connect equipment according to Figures 7, 8, or 9 as applicable to the specific frequency required. Figure 7 covers the frequency range of 1.0 to 8.0 GHz, Figure 8 covers 8.0 to 12.4 GHz and Figure 9 from 12.4 to 40.0 GHz.

NOTE

Throughout this lesson when the term "applicable frequency" is used, it means those frequencies within the range of the test item (TI). Normally it is only necessary to check a thermistor mount at a frequency near the high end, center and low end of its frequency range unless certification at specific frequencies is requested. TI's which have been repaired should be checked at all traceable frequencies within their range limits.

(2) Adjust the signal source (A7) for a frequency near the low end of the item's response range.

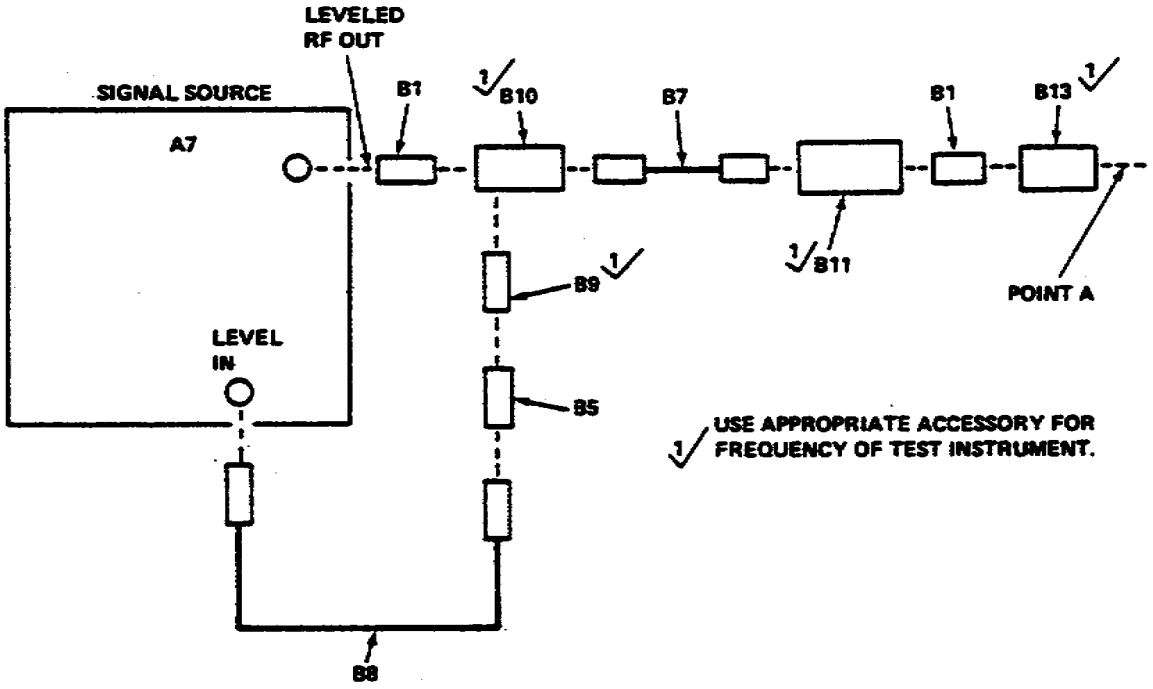


Figure 7. Calibration factor - equipment setup (1.0 to 8.0 GHz, transfer level).

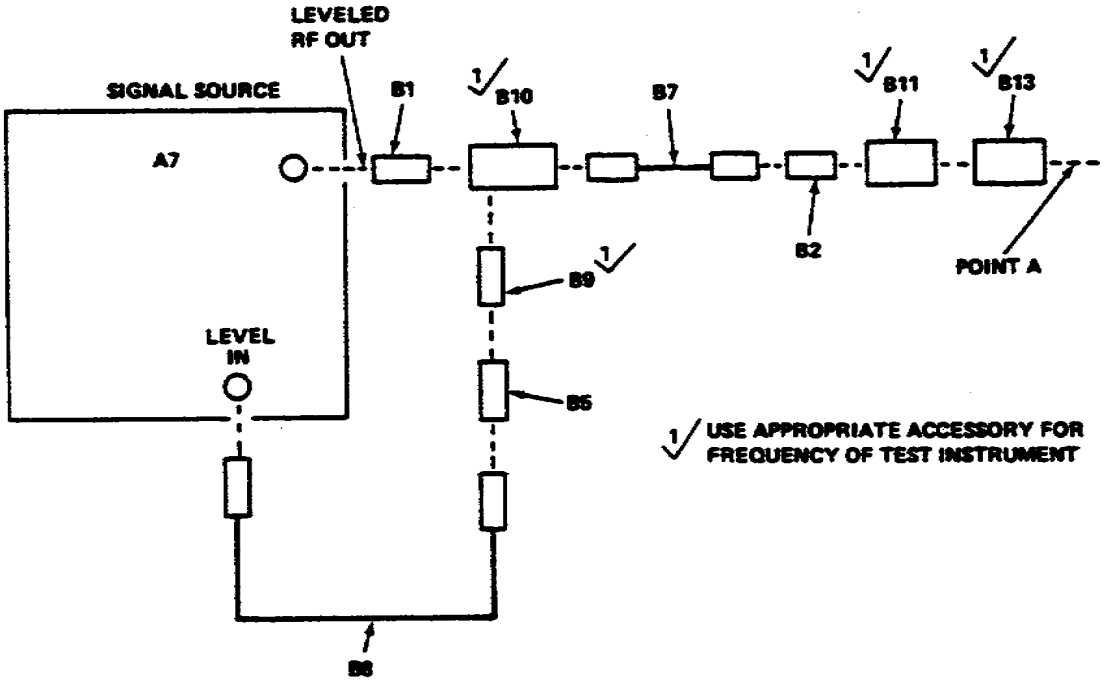


Figure 8. Calibration factor - equipment setup (8.0 to 12.4 GHz, transfer level).

(3) Connect the standard thermistor mount (AB) corresponding to the frequency range of the TI to power meter (A5).

(4) Turn the calibration factor percent control on the power meter to the valve indicated on the mount corresponding to the frequency selected in (2) above.

(5) Select the appropriate mount resistance switch setting and energize the power meter.

(6) Allow sufficient time for the power meter to stabilize and then perform the zero adjustment.

(7) Connect the mount to point A in the equipment setup in Figures 7, 8, and 9.

(8) Adjust the variable attenuator (B13) to obtain a full-scale indication on the 1 milliwatt range of the power meter.

(9) Disconnect the mount from point A without disturbing the signal source output level established in (8) above.

(10) Deenergize the power meter and disconnect the thermistor mount (A8).

NOTE

The procedure just described has standardized the equipment setup for calibration of the test item. Except for warmup period of the power meter, each time power is applied to or taken away from the mounts, wait approximately 3 minutes to allow the mounts to stabilize before continuing the procedure.

(11) Connect the rest mount to the power meter and turn the calibration factor percent control to 100.

(12) Energize the power meter and allow sufficient time for stabilization, then perform the zero adjustment.

(13) Connect the test thermistor mount to point A of the equipment setup.

(14) Record the indication on the power meter as the mount calibration factor percent.

(15) Disconnect the TI from Point A and deenergize the power meter.

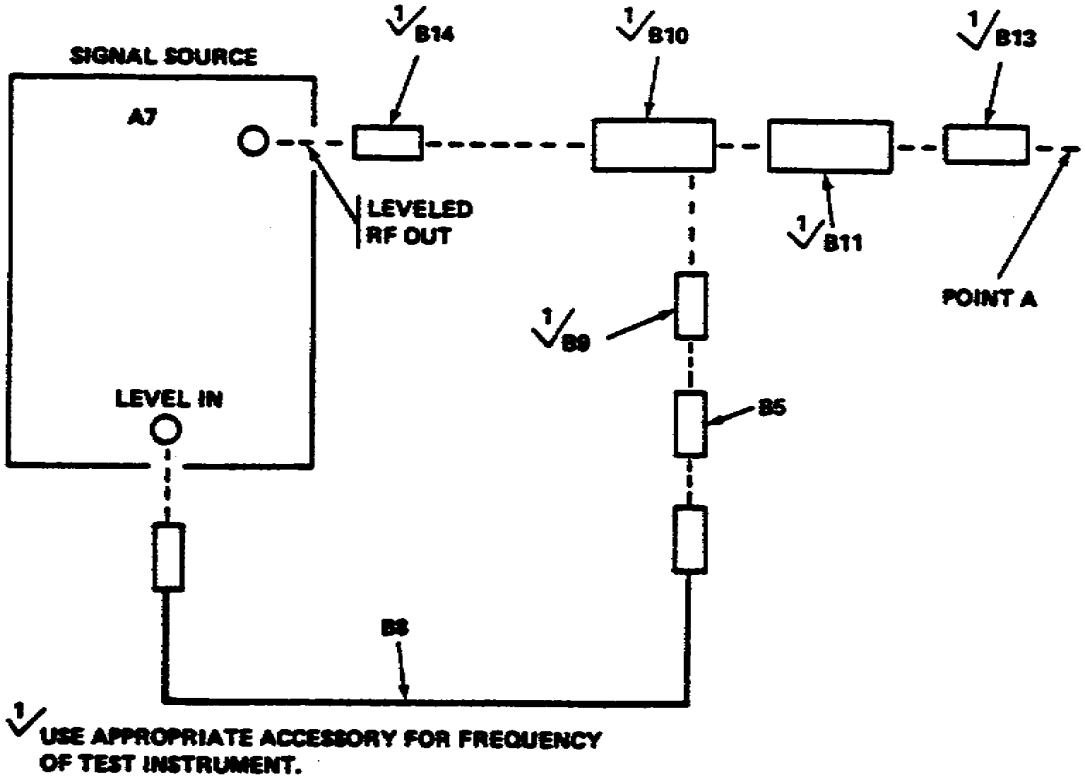


Figure 9. Calibration factor - equipment setup (12.4 to 40 GHz transfer level).

(16) Repeat steps (1) through (14) above for a frequency near center and one at the upper end of the TI response range.

(17) The value recorded in (14) above will correspond to the calibration factor stamped on the factor chart of the TI within ±5 percent.

8. REFERENCE CALIBRATION TECHNIQUE

a. This procedure deals with the reference technique in calibrating mounts. The technique we will describe is the preferred method. Once again the signal source is from the AN/USM 234 Test Set covered in ORD Subcourse 471.

b. Calibration Factor, 10 MHz to 18 GHz.

(1) Connect the equipment as shown in Figure 10, connection A, for the applicable frequency of the TI.

(2) Set the power meter (A5) and power bridges (A4) mount resistances to agree with the thermistor mount being calibrated.

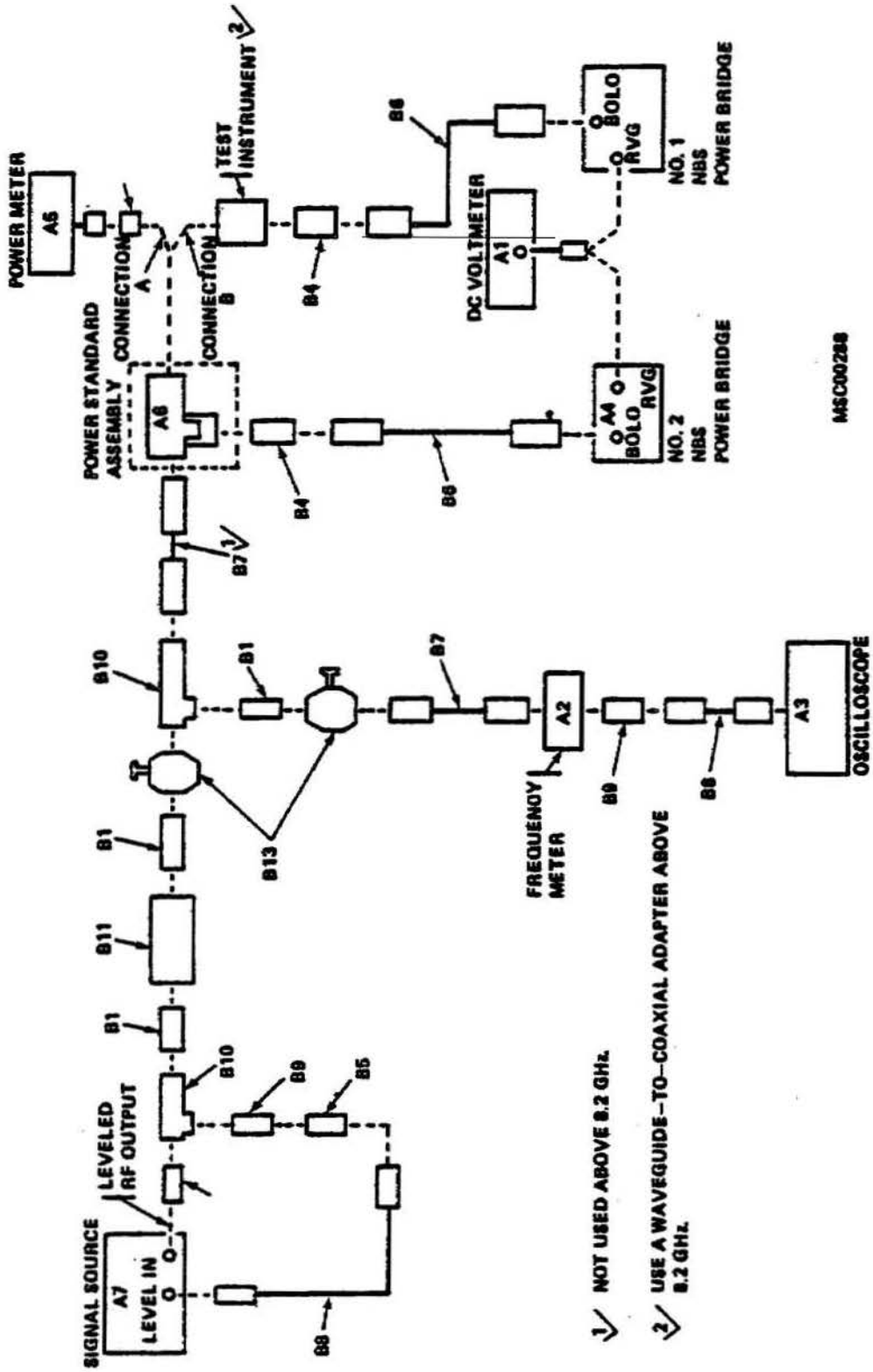


Figure 10. Calibration factor (10 MHz to 18 GHz reference technique).

(3) Set the signal source (A7) AC power switch to ON and energize the remaining instruments and allow 15 minutes for warmup.

(4) Adjust the main line variable attenuator (B13) for 20 milliwatts on the power meter. Connect the equipment as shown in Figure 10, connection B.

NOTE

Throughout this procedure, monitor the frequency during power applied measurements, using frequency meter (A2) and oscilloscope (A3).

(6) Disconnect cable (B7) from power standard assembly (A6).

(7) On each power bridge, place the reference generator function switch to NULL and the V-REM-ΔV switch to V.

(8) Place the reference generator function switch on each power bridge to the RVG position (fully-counterclockwise).

(10) Measure the voltage at each power bridge RVG terminal, using DC voltmeter (A1). Record the voltage at bridge number 1 as V_1 and the voltage at bridge number 2 as V_2.

(11) Reconnect cable (B7) to the power standard assembly.

(12) Set the V-REM-ΔV switch on both power bridges to ΔV. Measure and record the voltage at bridge number 1 as ΔV_1 and number 2 as ΔV_2.

(13) Compute and record the power ratio, applying the valves recorded above to the following formula:

$$\text{RATIO} = \frac{(2V_1 - \Delta V_1)\,\Delta V_2}{(2V_2 - \Delta V_2)\,\Delta V_2}$$

(14) Disconnect the TI from the power standard assembly and then reconnect it to the power standard assembly.

(15) Repeat (6) through (13) above.

(16) Deenergize the two power bridges and exchange the cables connected to their BOLO terminals.

(17) Energize the bridges.

(18) Repeat (6) through (15) above.

(19) If the valves recorded above are constant within ±0.3 percent, multiply the average of the four readings by the calibration factor of the power standard assembly at the applicable frequency. To obtain the calibration factor in percent, multiply the result by 100.

(20) Repeat steps (1) through (19) above for all required frequencies within the range of the TI.

(21) The calibration factor computed in (19) above for each frequency checked will be within ±3 percent of the calibration factor indicated on the TI.

c. Calibration Factor, 18 to 40 GHz.

(1) Connect the equipment as shown in Figure 11, connection A, for the applicable frequency of the TI.

(2) Set the power meter (A5) and she power bridge (A4) mount resistance for 200 ohms.

(3) Set the signal source (A7) AC POWER switch to ON, energize the remaining instruments, and allow for warmup.

(4) Set up the signal source for a phase-locked leveled output at the applicable frequency of the TI.

(5) Adjust the main line variable attenuator (B313) for 10 milliwatts below 26.5 GHz on power meter (A5) or for 5 milliwatts above 26.5 GHz.

(6) Connect the equipment as shown in Figure 11, connection B.

(7) Disconnect thermistor mount (A8) from directional coupler (B10).

(8) On the power bridge, place the reference generator function switch to NULL and the V-REM-ΔV switch to V.

(9) Adjust the reference generator divider dials for a null on the reference generator meter.

(10) Place the reference generator function switch on each power bridge to the RVG position (fully counterclockwise).

(11) Measure the voltage at the RVG terminals of power bridge (A4), using DC voltmeter (A1). Record the voltage as V_1.

(12) Reconnect the thermistor mount to the directional coupler from which it was disconnected in (7) above.

(13) Measure and record the RVG voltage as ΔV_1.

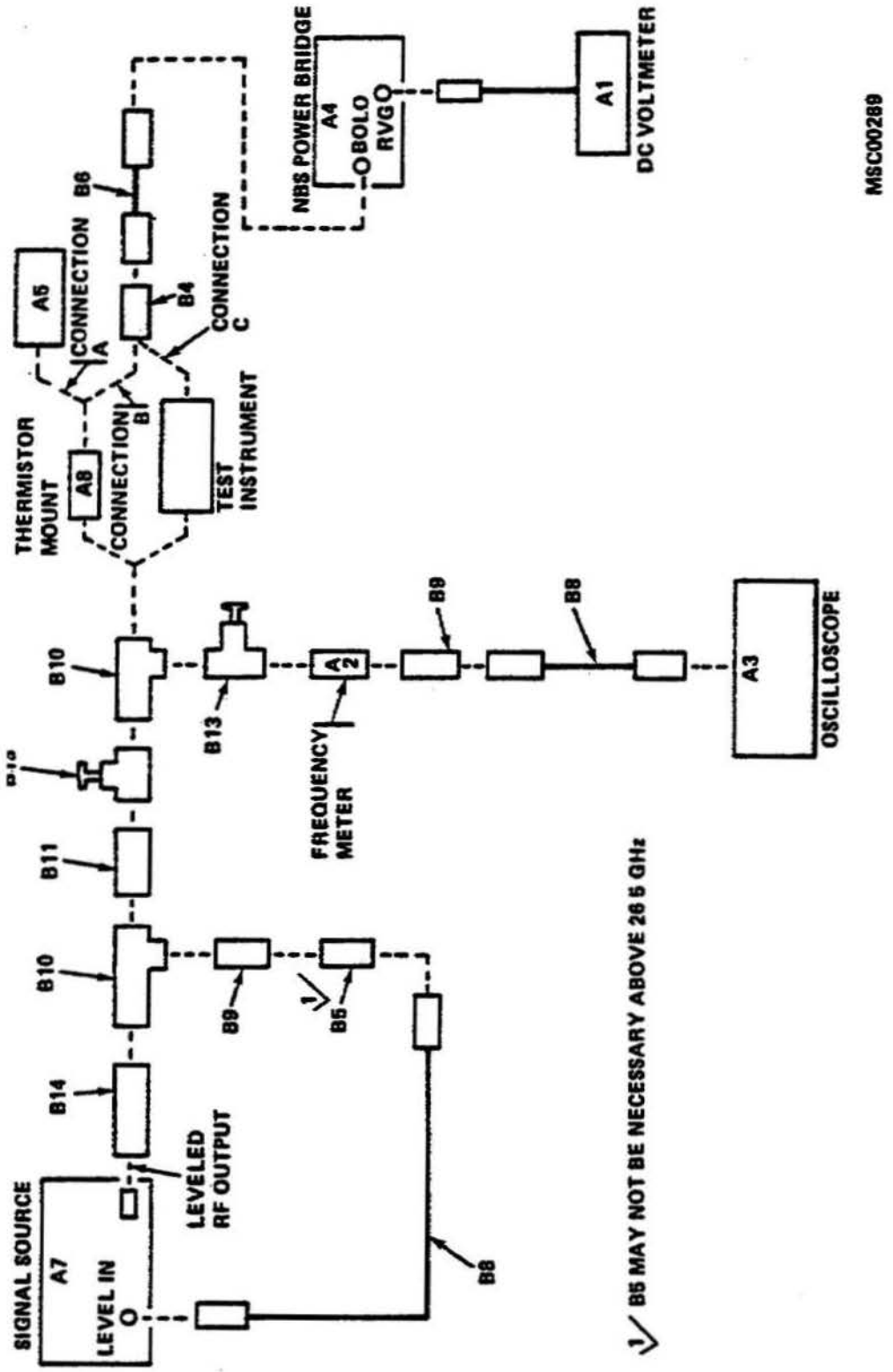


Figure 11. Thermistor mount calibrator factor (18 to 40-GHz reference techniques).

(14) Disconnect and reconnect thermistor mount (A8) from directional coupler (B10).

(15) Repeat steps (8) through (13) above.

(16) Deenergize the power bridge and connect the equipment as shown in Figure 11, connection C.

(17) Energize the bridge.

(18) Repeat steps (7) through (15) above, substituting the TI for the thermistor mount (A8). Record the voltmeter readings as V_2 and V_2.

(19) Solve the following equation:

$$\text{RATIO} = \frac{(2V_1 - \Delta V_1)\,\Delta V_1}{(2V_2 - \Delta V_2)\,\Delta V_2}$$

Where:

V_1 and ΔV_1 = average of the voltmeter readings applicable to thermistor mount (A8).

V_2 and ΔV_2 = average of the voltmeter readings applicable to the TI.

(20) Multiply the computed ratio by the calibration factor of thermistor mount, A8, at the applicable frequency. To obtain the calibration factor in percent, multiply the result by 100. The result will be within ±3 percent of the calibration factor indicated on the TI.

(21) Repeat (1) through (20) above for other required frequencies.

9. SUMMARY.

Now that you understand the measurement techniques used so make power measurements you will be able to make microwave power measurements in the future using appropriate procedures. The knowledge you have gained during the study of this subcourse has given you a foundation on which to build. Additional experience gained in the field and additional knowledge which you gain from technical publications will enable you to become an expert in microwave power measurements.

AIPD SUBCOURSE NUMBER MM0474, POWER MEASUREMENTS
EXERCISES FOR LESSON 5

1. At which point(s) should the frequency be calibrated on a thermistor mount?

   a. Low, center, and high frequency ranges
   b. Low frequency range only
   c. Center frequency range only

2. What value is obtained by calibrating a thermistor mount?

   a. Frequency range
   b. Power limits
   c. Calibration factor

3. What is the purpose of the main line variable attenuator used in the reference technique procedures for calibrating thermistor mounts?

   a. Provides phase-locked leveled output
   b. Adjusts for power output at specific frequencies
   c. Increases or decreases the calibration factor of the test instrument

4. What position should the RANGE switch be in on the model 431C, when adjusting zero control for 25% to 75% of full scale?

   a. Null
   b. 0 dBm
   c. 0.01 mW

5. During initial set up for a power measurement, what position should the CALIBRATION FACTOR switch be in?

   a. Position stamped on label of thermistor mount
   b. 88% position
   c. 100% position

6. For making a DC substitution power measurement, how should the signal source be operated?

   a. Square wave modulated
   b. CW mode (unleveled)
   c. CW mode (leveled)

7. Using a calibration factor while calibrating the Model 432A Power Meter, the digital voltmeter reads 0.920 volts. What position should the calibrator factor switch be in for an in tolerance reading?

   a. 94
   b. 97
   c. 95

8. Which formula should you use to calculate power when making meter accuracy test on Model 432A without a power meter calibrator?

   a. $$P = \frac{(V_{comp} + V_{rf})}{(V1)}$$

   b. $$P = \frac{(V1)\ (V_{comp} + V_{rf})}{800}$$

   C. $$P = \frac{(V_{rf})\ (V_{comp} + V1)}{800}$$

9. Using the reference technique from 10 MHz to 18 GHz, what percent of accuracy of the test instrument should be obtained?

   a. 5%
   b. 0.3%
   c. ±3.0%

10. What is the purpose of the standard thermistor mount (A8) in the calibration procedure?

    a. Standardizes equipment setup for calibration of test instrument
    b. Verifies the accuracy of the power meter
    c. Verifies calibration factor of test mount

11. In Figure 1, what is the purpose of the attenuator inserted between the power source and thermistor mount?

    a. To assure an input level of less than 1 mW
    b. To measure power levels above 10 mW
    c. To assure a stable power level

12. What precaution should be taken before changing the setting of BARR-THER switch on the NBS II Power Bridge?

    a. Energize power bridge
    b. Deenergize power bridge
    c. Select frequency to be used

13. When making the pre-operation setup on the NBS II power bridge, when should the bolometer be connected to bridge?

    a. After completing pre-operation setup with power off
    b. Before starting pre-operation setup with power off
    c. Before starting pre-operation with power on

14. What is the formula determining the Kb factor of UUT, when using the NBS II power bridge?

    a. $$Kb = \frac{\text{UUT mW}}{\text{Std mW}}$$

    b. $$Kb = \text{UUT(MW)} \times \text{Std (mW)}$$

    c. $$Kb = \frac{\text{Std mW}}{\text{UUT mW}}$$

AIPD SUBCOURSE NUMBER MM0474
APPROVED SOLUTION

LESSON 1.....Introduction to Power Measurements

1. b (para 2 a(1)
2. a (para 2 d(1)
3. c (para 2 b(3)
4. c (para 2 d(3)
5. b (para 2 a(1)
6. a (para 2 b(3)
7. b (para 2 b(5)
8. c (para 2 c(1)
9. a (para 2 c(2)
10. a (para 2 c(1)

LESSON 2.....Power Measurement Equipment - Part I

1. b (para 2h(2)
2. a (para 2 b(6)
3. c (para 2 b(6)
4. c (para 2 e(11)
5. a (para 2 e(2)
6. c (para 2 e(3)
7. b (para 2 f(1)
8. c (para 2 f(2)
9. b (para 2 b(3)
10. a (para 2 i(4)
11. b (para 2 g(3)
12. c (2n)
13. c (para 3 d(5)
14. a (para 3 e(4)
15. b (para 4 a(2)
16. b (para 5 d)
17. c (para 2 b(4)
18. a (para 3 g(2)
19. c (para 3 c(2)
20. b (para 3 f(3)
21. c (para 2 b(2)
22. a (para 2 e(2)
23. b (para 2 e(11)
24. c (para 5 c)
25. b (para 2 e(1)

LESSON 3.....Power Measurement Equipment - Part II

1. a (para 1 a)
2. c (para 2 b)
3. a (para 2 c)
4. b (para 6 a)
5. c (para 2 b)
6. c (para 6 c(1))
7. c (para 2 b)
8. a (para 5 d)
9. c (para 5 d(4)
10. c (para 5 j)
11. a (para 6 a(1)
12. c (para 6 a(2)
13. a (para 6 c(2)
14. a (para 5 j)
15. a (para 6 a(1)

LESSON 4.....Power Measurements III

1. a (para 2b)
2. a (para 3a)
3. b (para 3 b(14)
4. c (para 4a)
5. a (para 4 a(1)
6. b (para 4 b)
7. a (para 4 c(4)
8. c (para 2 c)
9. c (para 7 b(1)
10. b (para 7 g(1)
11. a (para 7 g(8)
12. c (para 7 h(3)
13. b (para 7 h(3)
14. c (para 8 a(3)
15. a (para 8 a(3)
16. c (para 8 a(6)
17. a (para 7d)
18. a (para 2a)
19. a (para 7a)
20. b (para 5a)

LESSON 5.....Power Measurements

1. a (para 7 b(1)
2. c (para 7)
3. b (para 8 b(4)
4. c (para 2 b(2)
5. a (para 2 b(2)
6. c (para 4 b(2)
7. c Table 1
8. b (para b (1)(h)
9. c (para b (21)
10. a (para 2 Note)
11. b (para 2 a)
12. b (para c 1(a)
13. a (para 6 1(d)
14. a (para 6 3(c)